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# A panacea to unsustainable consumption? A review of resource caps

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## Abstract

**Non-technical summary.** Many of the most pressing issues of today, such as climate change, habitat destruction, and conflict, are linked to our growing economies and the increasing amount of natural resources needed to maintain them. Current resource management policies focus on using resources more efficiently while maintaining economic growth. However, these policies have been insufficient and alternatives are needed. Resource caps are one such alternative which would directly limit resource consumption and extraction. This first review on the topic covers existing research on resource caps, the practical issues of implementation, and suggests a way forward for future policy and research.

**Technical summary.** Increasingly unsustainable rates of resource consumption and extraction have led to a growing discussion among researchers and environmental advocates on introducing caps on resource use. Research suggests that a reliance on efficiency-based approaches and a focus on decoupling are not sufficient to reduce ecosystem pressures, and instead alternatives such as resource caps may be needed. This article therefore provides the first comprehensive review of research on resource caps, linking them to major social science debates on resource scarcity, social metabolism, decoupling, and degrowth. Resource caps have been increasingly proposed in contemporary degrowth research, but this review found that resource caps are compatible with the agendas of those who endorse 'green growth' or 'ecomodernist' positions. Although resource caps are commonly proposed at a global level, it was found that enacting national or regional level caps is more viable, and that such caps should be developed through post-normal science and with democratic governance. However, current research does not show how resource caps can be implemented in practice, despite there being a detailed discussion on the political and social factors surrounding implementation. Future research will need to consider how, and even if, caps can function, and in what situations they are effective.

**Social media summary.** Capping consumption and extraction of natural resources is an alternative to current efficiency-based resource policies.

## 1. Introduction

Civilizations have been built on natural resources, with key resource requirements altering over the centuries. Although some access to resources will be needed in the future, a reduction in the associated carbon emissions and other forms of pollution are key goals of current global politics. Resource extraction and consumption are two of the most significant drivers of environmental change globally (Steinberger et al., 2010). They have been recognized under sustainable development goal 12: 'Ensure sustainable consumption and production patterns' (United Nations, 2015). Resource extraction and consumption has been linked to issues as diverse as climate change (Ivanova et al., 2015), conflict (e.g. Le Billon, 2001), and habitat destruction (Otero et al., 2020). Through these linkages they directly affect several planetary boundaries, including climate change, biogeochemical flows, and the erosion of biosphere integrity (Steffen et al., 2015).

To limit climate change, caps, limits, and quotas have been proposed and implemented to reduce carbon emissions (e.g. Liu et al., 2015; Zakeri et al., 2015). There is an extensive body of academic discussion on this topic. For example, Chakravarty et al. (2009) outline a possible framework for setting up national-level carbon caps through assessing the emissions of individuals. Quotas and permit systems have also been used to manage fisheries and freshwater (e.g. Cryer et al., 2016; Loch et al., 2018). Similarly, caps on resource consumption or extraction have been suggested as an approach to reduce resource use for minerals and for general material use. Resource caps have been increasingly listed as an option to deal with resource consumption, particularly from within the degrowth literature (Cosme et al., 2017). This article provides the first review of the interdisciplinary research on resource caps, as distinct from caps on pollutants such as carbon, in order to summarize and analyze the growing literature on this topic.

'Resource caps' generally refers to limits placed on how much of a resource can be used in a defined spatial area over a set time. They can take the form of upstream production caps limiting how much of a resource can be extracted, or as consumption caps limiting the quantity of a resource that can be used or imported (Alcott, 2010). Resource caps were proposed by ecological economists such as Herman Daly and others (e.g. Daly, 1974; Wetzel & Wetzel, 1995), who viewed them as a tool to help create a steady-state economy through reducing resource consumption and extraction, and allowing renewable resources to regenerate while encouraging substitutes for non-renewable resources (Daly, 2015). Although a relatively new idea, it does relate closely to rationing, which has been discussed extensively by post-war neoclassical economists. For example, Tobin (1952) viewed rationing as 'the replacement of a single-currency system with a multiple-currency system' (p. 521), and claimed that the major difference between these currencies is that the size of a ration is independent of labor inputs. However, a key difference in focus is that these early discussions of rationing focus more on the distribution of products, such as food coupons during a war, whereas a cap focuses more on distributing allowances to consume limited quantities. This is where more recent ration work is more relevant, for example the rationing of water use during drought in Australia (Grafton & Ward, 2008). Moving on from discussions of rationing, apart from the early work of steady-state economists, the idea of resource caps targeting non-renewable resources beyond the context of carbon caps was not discussed in detail again until an article by Alcott (2010) in which he argued for caps as they could directly target environmental impact, whereas many other policies aim to indirectly reduce environmental impact via addressing population, affluence or technology. (Alcott refers to and criticizes the popular 'I=PAT' formula, referring to impact, population, affluence, and technology, respectively.) The implementation of caps on pollution and carbon emissions has resurfaced the debate.

Although 'resource caps' is the most common name used, in the literature they have also been referred to as 'impact caps' (e.g. Alcott, 2010), 'depletion quotas' (e.g. Daly, 1974), or as 'diminishing resource caps' by Alexander and Gleeson (2019) to emphasize that mandated resource use should contract in size over time. Although quotas and permits are functionally similar terms to caps, in practice these have been used to refer primarily to renewable resources such as fish or water, whereas a cap has been used more in the context of pollutants or non-renewable resources. Resource caps have been envisaged in a variety of ways, ranging from abstract global caps (e.g. Freire-González, 2021), to caps on specific resources (e.g. Kallis & Martinez-Alier, 2010) or even per-person capping of total materials (e.g. Lettenmeier et al., 2014). There are different ideas of how caps should be implemented, whether they should be based on a scientific-expert assessment of depletion, renewal, and waste rates (e.g. Daly, 2015) or come about through democratic deliberation and agreement (e.g. Buch-Hansen & Koch, 2019; Kallis & Martinez-Alier, 2010; Schmelzer et al., 2022).

Over the last decade, caps have predominantly been discussed by scholars associated with the degrowth movement (see later). But there is little concrete discussion on what form these caps should take, what should be capped, and in what scenarios – if any – they may be appropriate. This review is the first to draw together and synthesize existing research on resource caps, and to highlight their contribution to policy and debate across several fields including geography, political ecology, human ecology, ecological economics, environmental economics, and resource economics. These debates are particularly relevant for academic debates on (a) social metabolism, (b) resource scarcity, (c) decoupling, and (d) degrowth.

Section 2 outlines the literature review methodology, and Section 3 discusses the current empirical research on caps. This includes research on the possible types of caps, current practice, and complementary policies. It will also outline some of the important social and political issues around setting and designing caps. Section 4 outlines the four areas of academic discussion that are closely linked to caps and existing linkages between these and resource caps. It then suggests future directions or synergies between each of these debates and research on resource caps. Section 5 provides recommendations for future research, which are centered around the questions of what political and institutional changes are needed for caps to be viable, and how would caps work in practice?

## 2. Methods

A traditional literature search combining a snowballing approach for past sources and searching citations for more recent sources was applied. As the cap literature is still relatively undeveloped, a systematic literature review or meta-review would not be useful as the sample size of viable articles would be too small. Additionally, a thorough systematic literature review was unviable due to the relevant key search terms such as 'cap' and 'quota' being used in many non-relevant contexts (e.g. dentistry and computing), making filtering of the results difficult.

Google Scholar and Scopus were searched for articles on caps using a variety of keywords such as 'cap', 'resource cap', 'impact cap', 'depletion quotas', 'extraction cap', and 'consumption cap'. I read through all relevant articles, of which 18 explicitly discussed resource caps, noting down main results, theoretical frameworks, and threads of discussion. Afterward, I grouped related findings and topics in order to structure my results and discussed in the context of relevant literature not explicitly discussing caps. The reference lists and citing articles were checked, with additional work found in ecological economics. Alcott (2010) was the main article on caps, and most relevant articles cited him. Some recent cap-related academic literature studies only mention caps in passing (see Section 4) and were hence excluded. The main focus was on contemporary work, not the early concepts nor Daly's steady-state economy.

## 3. Empirical evidence on caps

In this section, I will begin with a comprehensive overview of contemporary academic writing on resource caps. I will then discuss the types of suggested caps and their relative merits, before moving onto the potential issues that could arise through the implementation of resource caps, particularly in relation to setting the cap and issues of freedom and co-option. Table 1 is a non-exhaustive list on the 18 most relevant recent articles discussing caps. The year 2010 was chosen as a base as there were few articles mentioning resource caps beyond steady-state economists before Alcott (2010) resurfaced the discussion. As such, almost all recent work on resource caps cites Alcott (2010) and mostly uses similar justifications for caps, albeit without often mentioning his IPAT argument (see above).

Although resource caps can take several different forms, the three main options are (1) domestic tradable quotas, often called

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**Table 1.** Resource cap-related peer-reviewed research since Alcott (2010)

| Article | Description |
|---|---|
| Alcott (2010) | Makes a case for impact caps as opposed to traditional right-side IPAT solutions predominantly focused on technological efficiency |
| Kallis and Martinez-Alier (2010) | Outlines some of the issues facing caps, including institutional design and the dangers of eco-authoritarianism |
| Kallis (2011) | Argues that successful caps will inevitably lead to a decline in growth, and that cap-and-trade systems accepted by policymakers and the public are likely to be unambitious |
| Kallis et al. (2012) | Suggests caps as an option for future research |
| Sekulova et al. (2013) | A successful degrowth approach would include resource caps |
| Lettenmeier et al. (2014) | Outlines a suggestion for a resource cap on Finland's household consumption |
| Martinez-Alier et al. (2014) | Caps or taxes on raw material exports could help enable the transition to a more sustainable economy |
| Cosme et al. (2017) | Lists seven degrowth sources suggesting caps could be put on resource consumption and extraction |
| Freeman (2018) | Impact caps are a necessary part of a sustainable future |
| Heikkurinen and Bonnedahl (2019) | Caps are a promising sustainable alternative to dominant sustainability measures that focus on technological improvements |
| Zoellick and Bisht (2018) | Cites Alcott (2010) on impact caps as a strategy to directly address environmental impact rather than through indirect technological means |
| Henckens et al. (2019) | Suggests extraction quotas negotiated between small groups of companies on some critical resources |
| Otero et al. (2020) | Where caps occur, they should be at different levels of governance and include resources embedded in products and services |
| Stratford (2020) | Controls on rent-seeking and policies to redistribute rent could make resource caps more feasible |
| Freire-González (2021) | Advocates global limits on resource consumption using cap-and-trade |
| Keyßer and Lenzen (2021) | Gives caps and eco-taxes as an example of a degrowth policy that may lead to a shrinkage of GDP |
| Mastini et al. (2021) | Suggests resource caps as a possible component of a Green New Deal without growth |
| Schmelzer et al. (2022) | Supports democratically designed resource caps as an effective tool to reduce material consumption |

cap-and-trade, (2) an upstream auction where a cap is applied at the site of extraction and permits to extract under the cap are auctioned, and (3) a tax on resource production or consumption combined with lump-sum payments to consumers (Alcott, 2010). There has been little discussion or research on what kind of resource cap would work best, although there is theoretical and empirical evidence supporting each of these in the case of carbon (Boyce, 2018). In practice, whether a carbon policy is introduced upstream or downstream, and whether it is more economically efficient at addressing emissions or maintaining international competitiveness depends more on the specific design of the carbon policy, rather than whether it is more like a tax or cap-and-trade (Goulder & Schein, 2013). The main difference is that cap-and-trade leads to more price volatility as changes in demand can lead to major changes in price, whereas the main advantage of cap-and-trade over taxes is that it guarantees emissions will not surpass a set limit, which could happen with taxes if prices are not set correctly (Goulder & Schein, 2013).

Resource caps are typically discussed with only brief references to distribution (e.g. Schmelzer et al., 2022), or assume a cap-and-trade scheme will operate (e.g. Freire-González, 2021). Little reference is made to existing research on carbon cap-and-trade, but many of the conclusions on carbon caps would be similar for resource caps. For instance, allocating resource-use certificates equally to people and commercial entities without a trading mechanism is generally seen as economically inefficient within the literature (Grafton & Ward, 2008). However, there are arguments that such systems can be 'fairer' (Baumol, 1982).

In addition to the three main options, an alternative downstream approach involves rationing by individuals (Alcott, 2010). For example, Lettenmeier et al. (2014) suggested a per-person annual material footprint of eight tons per person in Finland would be sustainable. Resource caps that involve individual rationing focusing on high-income households are a similar possibility. For example, within the climate literature, Jaccard et al. (2021) found that in order to meet climate targets strategies such as capping high-income household energy use will be necessary. However, a policy closely monitoring the consumption of each individual may be seen as draconian in more democratic states where individual liberty may be highly valued, and unless enacted with broad public support may draw comparisons to China's Social Credit System. Additionally, it seems doubtful that such a system could accurately account for the vastly differing environmental impacts of different resources, particularly as current measurements of environmental impact such as material footprint, ecological footprint, and environmental performance index are incongruent (Requena-i-Mora & Brockington, 2021). This is much more complicated than with carbon where at the very least caps and other climate policies can be set to achieve certain carbon emission targets following for example the Paris 2050 1.5°C target (e.g. Jaccard et al., 2021).

Existing cap-and-trade systems, such as for carbon, tend to have lenient caps and light regulation to avoid increasing the

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cost of environmentally damaging but politically and economically important industries (Kallis, 2011). As such there are few if any examples of policies that strictly regulate overall resource consumption to what could be viewed as a sustainable level (van den Bergh, 2011). No examples of caps on minerals were found in the literature, but there are many examples of caps on carbon, such as the European Union Emissions Trading Scheme (EU ETS) (Álvarez & André, 2015). Caps have also been applied to some pollutants such as sulfur in the United States (Keohane, 2009) and to fisheries, like the total allowable catch limits in New Zealand (Cryer et al., 2016). Meub et al. (2016) discussed the potential application of cap-and-trade to land consumption in Germany, with set amounts of tradable certificates given to municipalities to use for building projects, but this has not been implemented.

It is argued that caps could be complemented by spatially constrained bans on extraction in areas where high biodiversity is affected, also limiting associated transport infrastructure expansion in those areas (Otero et al., 2020). This would help further limit impact on ecologically sensitive communities. These already exist where conservationists have successfully campaigned for bans on mining in some national parks and reserves such as in Zimbabwe (BBC, 2020).

### 3.1 Potential issues for cap implementation

There is a tendency to assume or envisage resource caps applied globally and set at differing levels for different individual states. For example, Freire-González (2021) suggests there should be global limits implemented through cap-and-trade. Schmelzer et al. (2022) propose caps as national or global ceilings on resource extraction. Alcott (2010) also envisages caps as global, and on per country rather than per individual basis. The former is to avoid any free-riding, and the latter is to account for population changes. Another reason given in support of global caps is that more localized caps set at smaller scales could experience rebound effects through imports and trade (Santarius, 2012). For example, the effect of a cap in one place could be reduced if resource-intensive industries or investment funds are re-allocated to places not covered by the cap. However, unilaterally implementing caps is not a barrier to global progress toward a more sustainable global economy. Although not necessarily supporting resource caps, or even carbon cap-and-trade instead of carbon taxes, Edenhofer et al. (2015) argued that, in the case of carbon, the unilateral introduction of different emission pricing systems by states could allow for incremental progress toward international agreements. The same arguments can be applied to unilaterally enacted resource caps.

Although global caps are theoretically optimal, they are difficult to realize. It is difficult to envisage global caps on resource use when even global action on lowering carbon emissions is a divisive issue. States have different and competing national and economic interests surrounding resource governance that would complicate discussions and agreements. Considering that many resources have more localized environmental impact than carbon or ozone-depletion substances, it would be more difficult to appeal to any narrative of necessary international co-operation. Additionally, there is evidence in the case of carbon, particularly during early attempts to link European, Californian, and Quebec carbon markets, that when more than one national entity controls the market, it can be unstable and difficult to manage (Green, 2017).

Generally it has been assumed that resource caps, even if global, would be set or determined nationally or on similar scales (e.g. Alcott, 2010). The existence of large multinational companies and highly mobile wealthy elites does lend credence to the idea of caps on larger scales. On the other end of the spectrum, there is room to investigate caps on smaller scales, such as at a city or community level. However, this review follows the literature in focusing on caps at the level of a state. Although recognizing that caps at other scales may be viable and are worthy of investigation, they face a completely different set of problems to state-based caps, ranging from potentially lacking the legal, institutional, and practical power to set and enforce caps, to difficulties in tracking and monitoring capped resource flows across boundaries. Furthermore, current governance of resource use is predominantly at national or sub-national scales (Henckens et al., 2019), managed under national-scale property rights (Bringezu et al., 2016). This favors national-scale implementation of caps. Although there is no evidence in the literature of resource caps on minerals having been implemented at any scale, there are a variety of caps or permit schemes on national or sub-national scales that can be of instructional value in designing resource caps (e.g. Cryer et al., 2016; Keohane, 2009).

Unilateral implementation of extraction caps could result in complicated geopolitical outcomes. China's export restrictions on rare-earth metals implemented in 2010 is an example of the potential effects of such a unilateral approach (Klossek et al., 2016). Nations may be less likely to implement an extraction cap in case it interferes with free-trade arrangements or leads to a deterioration in partnerships. As such, in many cases caps on resource consumption of imported resources may be more politically and practically viable. For example, a hypothetical cap on a rare-earth resource used in a country that does not produce it would occur at the end of a supply chain and not affect as many actors, but would reduce a country's reliance on that resource, whereas a cap on the same resource at the point of extraction would affect many actors down the supply chain and have more potential for stoking geopolitical tension. In essence, depending on the resource, extraction caps are more likely to have more globalized in terms of reducing environmental impact and but also increasing geopolitical tension than with consumption caps.

Beyond the scale of the cap, an important question is who will determine the level of caps, and how they will do so (Kallis & Martinez-Alier, 2010). Steady-state economists (e.g. Daly, 2015) tend to adopt a discourse addressed at 'enlightened' knowledgeable policymakers and scientists. In contrast, others, particularly within the degrowth movement, see implementation as comprising values as well as science, questioning decision making and implementation models that involve sequestered policymakers and experts making decisions without transparency or democratic involvement (e.g. Kallis & Martinez-Alier, 2010). There are many examples of purely science-driven water and fishery policies that have been unsuccessful (Kallis & Martinez-Alier, 2010). The analysis of Buch-Hansen and Koch (2019) of a wealth and income cap strongly supports caps being democratically developed through participatory settings involving different societal groups, rather than being dictated by policymakers and experts. Fuchs et al. (2021) provide a discussion of potential participatory approaches and emphasize the need to treat people as holistic individuals rather than consumers to be influenced, and also emphasize the necessity of promoting 'citizen competence' to empower citizens in discussing potential societal futures and pathways.

There are many factors that could influence the level at which a cap is set. These range from a scientific assessment of the impact of a certain level of resource use, to an agreement drawing on what is politically acceptable, as seen in the case of the Paris Agreement (Geden, 2016). One common suggestion for resource or other caps is that they could relate to historical levels of consumption and environmental impact by country (Otero et al., 2020; Schmelzer et al., 2022). This is a common narrative in carbon discussions (particularly for countries in the Global South including China) arguing that countries with large historical emissions should shoulder a higher burden of emission reductions. However, most of this discussion assumes global discussion around the setting of caps, and is more relevant to pollutants with globalized impacts. In the case of resource caps, which primarily would be on resources such as minerals with more localized impacts, the most relevant factors could be different than for carbon. For example, in the case of existing permit systems such as Australia's Murray-Darling Basin Plan and New Zealand's fishing permit system, discussion centered around ensuring clear and tradable property rights for water and on transgressions and non-compliance for the former and on long-term environment and economic sustainability in the latter (Cryer et al., 2016; Loch et al., 2018).

If trying to reduce overall environmental impact, it is likely that several different caps on different resources or impacts would need to be set rather than an aggregate figure, with this rendering debate and decision making more complex, as has occurred for capping carbon emissions (Kallis & Martinez-Alier, 2010). Whether such caps should be at a fixed level, vary based on some criteria, or diminish over time has been discussed very little (e.g. Alcott, 2010; Alexander & Gleeson, 2019).

Another major issue that would hinder implementation of an aggregate cap on resource consumption is whether a cap could be enforced, as a cap that is not enforced would have little effect. An aggregate cap would be difficult to enforce as although economy-wide aggregate material flow analysis tools exist (e.g. Schaffartzik et al., 2014), it would still be almost impossible to monitor the extraction and movement of all materials. In terms of caps on specific resources then, enforceability would depend on three factors. The first is the institutional, legal, and practical powers of a state as it would need to have the power to implement and monitor a cap. The second is the type of resource being capped, it would need to be a resource that could be monitored at the point at which it is capped, for example this could be at the point of extraction, import, or export. The third is the distribution scheme, where for example certificate trading and auction might ensure easier monitoring and enforcing than in the case of directly allocating permits.

Alcott (2010) debated whether resource caps might infringe on individual freedom and whether such policies are politically acceptable. He claims that caps have no more risk of being used for authoritarian purposes than competing policy approaches such as taxation and setting penalties. Replying to Alcott's article, Kallis and Martinez-Alier (2010) suggested the process of setting and monitoring caps could result in eco-authoritarian and expert-based regimes, or draconian environmental regulation. They highlight that caps are particularly vulnerable to being used in this way due to their scientific complexity, vesting access to resources with the state, and suggest that popularly undesirable caps could be enforced by authoritarian regimes. Existing caps on carbon such as the EU ETS have been viewed as technocratic due to their heavy reliance on market mechanisms to solve environmental problems (Knox-Hayes & Hayes, 2014). Kallis and Martinez-Alier (2010) suggest that caps decided on through post-normal science (a collaborative process drawing on a combination of science and different interest groups) and democratic governance through communal institutions are possible, but that this process is potentially difficult and may result in caps quite different to those that have been theorized. This does raise the question of what a post-normal collaboratively designed cap would look like, and there is room for experimentation to see where this might lead.

We have established that the institutional changes needed for the implementation of a cap may be complicated (Kallis & Martinez-Alier, 2010). Structures to monitor, design, and enforce caps would be needed, especially to reduce the risk of co-option by corporations or for eco-authoritarian reasons. These could require large investment and would not necessarily by successful (Kallis & Martinez-Alier, 2010). Caps are only likely to succeed if there is significant legal or political support (Colby, 2000). Vested interests and strong links between politics and private interests make it difficult for meaningful policy change to occur (Kallis, 2011; Kallis et al., 2012).

Stratford (2020) highlights how rent-seeking behavior is an issue for any potential resource cap in a degrowing economy. She argues that scarcity induced through hard-environmental limits such as caps will increase prices, and that this will lead to a greater opportunity for rent capture. She views rent-seeking behavior as occurring when individuals and firms profit from controlling assets that are difficult to substitute, thus extracting rent and gaining far high-profit margins than would occur if an asset was more substitutable. For example, controlling land to lease to mining interests is an example of rent capture, whereas a new technological innovation is not as it could be copied in other companies. As such, she argues that rent-seeking prevention and redistribution measures are necessary to mitigate adverse social impacts of a cap, and would have the co-benefit of increasing popular support of such policies.

Due to the difficulties outlined above, Smith (2014) suggests that caps and similar hard environmental limits may not be possible without a radical societal restructuring and a move beyond capitalism. He argues that in some cases it would be simpler and more environmentally effective just to ban certain substances or practices outright. Others have also argued for the banning of excessive practices of the wealthy such as private jets or megaprojects such as hydro-power dams (Schmelzer et al., 2022). Again, such a perspective runs the risk of currently being politically and practically unfeasible in democratic nations. However, as the climate crisis worsens, and if other environmental issues become more acute, nations that have more dynamic democratic systems where new political parties and movements can emerge and take power may in the future be more likely to enact such policies than in authoritarian or in two-party democratic systems such as the United States and United Kingdom, as these policies would generally be against the entrenched interests of governments and elites.

## 4. Caps and social science debates

In this section, I will outline the background of the four social science debates listed in the Introduction and discuss how they link to current cap research. For each debate, I will then outline potential contributions research on caps could have to these debates, and the converse, how further developments in these debates can benefit future research on caps. I will begin with the discussion around the social metabolism, before moving on sequentially to resource scarcity, decoupling, and degrowth in turn.

### 4.1 The social metabolism

When it comes to discussions around social metabolism, the sustainability or lack thereof of global resource consumption has been debated for centuries. Arguably one of the first important works on this topic was Thomas Malthus's 1798 *An Essay on the Principle of Population.* The common interpretation of Malthus's argument is that population growth would eventually outpace agricultural production and available resources. However, a new reading suggests that Malthus was instead intent on discouraging revolutionary action seeking equality as a solution to problems of scarcity and in fact argued that continued productivity increases could under the right circumstances lead to continuous gains in agricultural productivity and population growth (Kallis, 2019). Recent discussion around global resource consumption and limits was made prominent by *The Limits to Growth* report of the Club of Rome (Meadows et al., 1972). Contemporary research within social and industrial ecology and ecological economics focuses on the 'social metabolism', which is the compilation of the continuous material and energy flows that allows society to function (Haberl et al., 2017; Mayer & Haas, 2016). This discussion has been ongoing owing to increasing rates of global resource extraction and consumption. For example, there has been a 30% increase in the global social metabolism in the first decade of the 21st century alone (Schaffartzik et al., 2014). Even under the most stringent degrowth futures the large-scale adoption of renewable energy will require large quantities of minerals (Gibon & Hertwich, 2014; Harmsen et al., 2013).

Resource extraction as a driving component of the social metabolism is a global issue, but it often plays out at local scales. Global demand for resources can lead to ecological distribution conflicts over resource access, ecosystem services, and of the location of pollution and waste outputs (Perez-Rincon et al., 2019). Ecological conflicts can lead to the erosion of livelihoods, conflict within and between communities, the displacement of communities, and even the death of local activists (Bringezu et al., 2016; Ide, 2015; Martinez-Alier et al., 2016; Tran et al., 2020). Ecological distribution conflicts are increasing in number as shown in the Environmental Justice Atlas project (Bringezu et al., 2016). These conflicts tend to be more potent in the Global South where there are less clearly defined property rights to land (Hilson, 2002). There is a further neo-colonial dimension due to many resource extraction activities being undertaken on the cultural lands of Indigenous groups, who are forced to interact with large corporations at a significant power disadvantage and with limited common ground in terms of culture and language (Perez-Rincon, 2006).

Current resource consumption levels are unsustainable according to social metabolic models. But policy outcomes from these findings are lacking. The general finding is that humanity needs to (a) increase the efficiency of resource use, or (b) reduce the size of metabolic flows (Fischer-Kowalski & Haberl, 2015). It is the next step, policy implementation, that could involve resource caps. Caps could aid in reducing the social metabolism (Martinez-Alier et al., 2014), and existing research on social metabolism acts as a rationale for reducing resource consumption and extraction (Schaffartzik et al., 2014). It has led to national-level indicators for monitoring resource use and consumption policies, and an international material flow database (Haberl et al., 2019). Such databases could be used to propose levels at which caps should be set based on historical levels as suggested by Otero et al. (2020). A detailed description of material flows can help encourage a transition to a more circular economy (Haberl et al., 2019). Proposals focusing on capping aggregate materials such as Lettenmeier et al.'s (2014) rationing proposal would likely have to use social metabolic assessment tools such as material flow analysis.

The social metabolic literature could benefit from a discussion of caps, as it provides one way to translate flow calculations into policy approaches. Although social metabolic tools are undoubtedly useful and perhaps necessary in gauging how to set caps, such tools can be scientifically complex and would require careful consideration on how to involve different layperson interest groups (Buch-Hansen & Koch, 2019; Kallis & Martinez-Alier, 2010). As such, the many social factors surrounding a cap in relation to social metabolism studies should be strongly emphasized. Such social factors could include, but are not limited to, inequality and wealth distribution, poverty and marginalization, transparency and accountability (e.g. Brand et al., 2021).

### 4.2 Resource scarcity

Resource scarcity and how to manage it has been discussed for decades. Hotelling (1931) was concerned with resource exhaustion and concluded that then-prevailing conservation methods such as mandating obsolete technology or implementing periodic temporary bans on extraction were economically inferior to taxation, and that taxation and interest rates should be set to optimize resource production. Much of the contemporary debate hinges on how likely resource scarcity is to occur in the near and long-term future and at what scale, whether markets, prices, and technological advancements are sufficient tools to manage scarcity, what forms scarcity may take, whether scarcity will have a significant impact across the planet, and how to manage it through policy intervention. In particular, there is an ongoing debate between thinkers such as Tilton (2003) who are 'modestly-optimistic' about future scarcity, and others for example Prior et al. (2012) who are concerned about increasing marginal costs and impending resource scarcity (e.g. Calvo et al., 2017; Wellmer & Scholz, 2018).

Tilton's (2003) idea is that increasing prices will drive technological innovation and mineral exploration, which will render more minerals economically viable to obtain. He claims that the issue is not resource depletion but is instead slowly increasing prices due to extraction becoming increasingly expensive. This position is commonly held by cornucopian thinkers such as Julian Simon who contest that human ingenuity combined with free markets have made resources less scarce, and will continue to do so (Aligica, 2009).

In contrast, Prior et al. (2012) argue that there are increasing marginal costs that constrain extraction but do not end it, with further extraction leading to increasing environmental and social costs (Memary et al., 2012; Prior et al., 2012; Wellmer & Scholz, 2018). They argue that although prices do correlate to some extent with scarcity (e.g. Tilton et al., 2018), they have proven to be a flawed proxy, for example in the cases of petroleum (Gordon et al., 2007) or fisheries (Akenji et al., 2016). Recent work in material science also undermines the confidence in human ingenuity to solve scarcity issues through new technological breakthroughs. Out of 62 metals used frequently in the global economy, none have existing exemplary substitutes, and many commonly used metals, such as copper and manganese, have no good substitutes at all (Graedel et al., 2013). Both sides of the debate acknowledge that resource scarcity is an issue, but differ on their assessment of the severity of the problem and what needs to be done to manage it.

Ostrom (1990) demonstrated that resources can be collectively managed sustainably over the long term by different users, challenging the then-prevailing notion that commonly held resources would be subject to rapid exhaustion unless private property rights were implemented, the well-known 'tragedy of the commons'. However, as Ostrom herself acknowledged (Ostrom, 2010), there are different diverse resource systems and no universalized rules. In the case of global fisheries, the original tragedy of the common arguments may be valid, and there have been continuous, and sometimes controversial, suggestions to create property rights and systems similar to caps, for example on whales (Costello et al., 2012). Even without the application of the tragedy of the commons argument, resource caps could prove to be a useful tool for pre-emptively managing scarcity. Related policy concepts such as quotas have been used for managing scarce renewable resources in fisheries (e.g. Cryer et al., 2016) and for managing water resources such as aquifers and rivers (e.g. Loch et al., 2018). Cap-and-trade systems have been implemented to manage and limit the quantity of emitted pollutants such as sulfur dioxide and carbon (e.g. Álvarez & André, 2015; Keohane, 2009). Quotas have been suggested as an approach to managing critical minerals, perhaps agreed upon by groups of countries that mine them (Henckens et al., 2019). However, resource caps are yet to play a significant role in the debate over resource scarcity for non-renewable resources such as minerals. This is surprising as Daly advocated resource caps as a way of encouraging the discovery and uptake of substitutes for scarce resources decades ago (Daly, 2015). That renewable resources have been managed under cap-like policies but not non-renewable resources could be due to their characteristics of being renewable or non-renewable themselves, with their being an incentive to manage renewable resources so they can be harvested perpetually, whereas with non-renewable resources extraction cannot continue forever. Furthermore, non-renewable extractive activities tend to be predominantly centered on mining, which operates on a shorter temporal scale than activities such as fishing and farming, as mines are not intended to operate indefinitely.

As with social metabolism, caps could be of benefit as a management or policy option toward dealing with scarcity – for example, the enormous demand for lithium at present for battery technologies might require a cap on production, rather than free-market price inflation fueling risky and polluting mining operations in dryland lake beds and other environments (Babidge et al., 2019; Jerez et al., 2021). Caps could be investigated as a policy option that could help address concerns over resource criticality, supply risks, vulnerability to supply restrictions, and concerns over resource exhaustion and lack of substitutes. Caps could act to reduce reliance and pre-emptively manage important resources such as phosphorus (e.g. Alewell et al., 2020) before any issues arise. A resource cap would in essence artificially induce scarcity earlier, but in a controlled manner through which it would be easier to deal with variability in resource supply as opposed to a situation of uncontrolled scarcity.

There have been long-term predictions of extractable resource exhaustion in economic, social, and environmental terms without proper management for resources such as gold, copper, and nickel (Henckens et al., 2019). There are also concerns over the long-term exhaustion and uneven build-up of important minerals for the biosphere, such as phosphorus (e.g. Cordell et al., 2009; Ragnarsdottir et al., 2011). Market pricing is unlikely to address longer term supply concerns (Henckens et al., 2019) and capping either production or consumption of phosphate fertilizers or depletion rates would help deal with issues of disruption sooner than they will arise. Similarly, caps could apply to resources with few effective substitutes such as magnesium, manganese, and chromium (Graedel et al., 2015), to drive scientific endeavors to find possible substitutes or to drive more efficient use.

The case of China's restriction of rare-earth metals in 2010 (Klossek et al., 2016) demonstrates that geopolitical concerns should be accounted for in any discussion of resource caps in the context of resource scarcity. Although China's restriction on rare-earth metal exports was undertaken for political reasons rather than to manage scarcity on the Chinese side, it does illustrate the kinds of economic and political ramifications a cap on a scarce resource can have, as Japan responded by drawing on resource reserves and attempting to diversify supply chains. In general, a resource cap encapsulating exports could affect importing countries and therefore damage relationships. In light of geopolitical concerns, there is an important discussion to be had surrounding whether implementing caps at the point of extraction, or at the point of import or consumption, would be better approaches for managing resource scarcity. A cap that came into effect further up the supply chain or at the point of extraction would be more likely to have wider geopolitical effects. In contrast the unilateral decision to restrict imports for environmental reasons may have less geopolitical ramifications as particularly for many scarce and high-impact resources such as phosphorus and rare-earth metals there are fewer locations where such resources are extracted and exported from compared to places they are imported to. However, this is not to say that an import cap would be without geopolitical implications as seen in the case of China's recent import ban on many Australian products.

### 4.3 Decoupling

How necessary it is to reduce resource consumption and extraction and how best to do so is a complex and topical issue, and there are two major camps. Mainstream 'ecological modernists' such as Ted Nordhaus tend to argue that societies can decouple economic growth from resource consumption, by scientific and engineering led technological advancement (e.g. Asafu-Adjaye et al., 2015). The possibility of decoupling is central to the idea of green growth (contested by Hickel & Kallis, 2019) supported by major institutions such as the World Bank, United Nations Environment Program, and the Organization for Economic Co-operation and Development.

In an investigation of 116 countries, Hubacek et al. (2021) found that 14 countries had managed to absolutely decouple both consumption- and production-linked emissions from GDP growth. Although there has been some success with emissions, there has been less success with material consumption in general. Despite large efficiency gains in the use of materials, there has not been a corresponding total reduction and absolute decoupling of material use (Shao et al., 2017). Although absolute decoupling could occur in the future (Meyer et al., 2012), in recent years even trends toward relative decoupling have often been reversing (Krausmann et al., 2018). For proponents of decoupling, if it is possible then it should be possible to achieve economic growth under a resource cap. As such, introducing resource caps could also be used to validate the realizability of decoupling. However, there is no empirical evidence supporting the possibility that global decoupling of resources or emissions can occur globally and at a rate necessary to limit climate change in line with the Paris goals (Hickel & Kallis, 2019). This is a major reason why policies such as caps have been suggested as options to manage consumption and emissions.

Critics of the decoupling idea, often endorsing degrowth precepts, believe that it is not possible to decouple economic growth from resource consumption at a rate sufficient to avoid loss and damage of ecosystems. This academic argument has major practical implications, as if it is not possible to decouple material consumption from economic growth then new approaches, such as those suggested by degrowth proponents, are required. Even beyond degrowth circles, related ideas have become more mainstream, with the concept of 'sufficiency' appearing in the IPCC 6th Assessment Report, which defines it as a 'set of measures and daily practices that avoid demand for energy, materials, land, and water while delivering human well-being for all within planetary boundaries' (IPCC, 2023, p. 72). If decoupling is not possible, then continuous expansion of material affluence would not be possible, and sufficiency would need to be the focus, with resource caps being a policy approach that could help achieve it.

Indeed, and especially if the decoupling argument is unconvincing, there is a need to investigate and implement more socially acceptable approaches to reducing resource consumption and extraction and managing scarcity (Gorg et al., 2019). If decoupling is not possible, then policies compatible with degrowth such as resource caps may be needed to reduce material consumption. However, even if there is a consensus supporting the introduction of policies such as resource caps, political economy constraints are important. The repeal of Australia's ETS, in essence a carbon cap, provides an illustrative case study of such issues. After being discussed since 1997, in 2007 the introduction of an ETS became the bipartisan policy of Australia's two major parties. It took a further 5 years and one failed attempt for carbon pricing to be eventually introduced in 2012, but without bipartisan support (Crowley, 2017). However, a conservative government was elected in 2013 after running a campaign targeting the ETS and repealed the program. As such, this case study shows that popular and political support can change, and that policies can take a significant time to move from conceptualization, to policy, to implementation. Furthermore, there are issues of path dependency, where even if new policies are introduced it can take time to change direction (Djelic & Quack, 2007). There has been extensive discussion on how these types of political economy issues relate to decoupling and degrowth in the literature (e.g. Djelic & Quack, 2007). As such, although alternatives to decoupling may be required, these too face significant constraints around implementation.

Caps have been discussed in the context of decoupling, specifically as a way of mitigating the rebound effect. The rebound effect is when increases in resource-use efficiency are reinvested in further resource-consuming activity and as such the originally efficiency savings are reduced (Alcott, 2005). Caps are theoretically the most effective approach for reducing rebound effects as money saved from becoming more efficient at using a resource or else cannot be reinvested into continued extraction or use of that resource (Santarius, 2012). Caps are viewed by Vivanco et al. (2016) as being more attractive than taxes as they address impact directly, rather than increasing efficiency, which does not always lead to absolute reductions in impact. Freire-González (2021) explicitly suggests cap-and-trade as a way of addressing the rebound effects of reducing resource use. However, Santarius (2012) cautions that caps that are not on a global scale may not prevent rebound through imports and trade.

The effects of implementing resource caps could have direct significance to theoretical debates surrounding decoupling. Although one of the justifications for implementing caps is the view that a sustainable rate of decoupling is impossible, the success of resource cap policies is independent of whether decoupling is possible. In other words, the success of a cap would be judged by whether material consumption does decrease regardless of whether it hinders or aids economic growth.

In fact, resource caps could provide evidence on decoupling, by acting as a litmus test. If stringent caps, whether on aggregate material use or targeting multiple resources with a high-environmental impact were implemented in several places, the effects on GDP would form empirical data for further evaluating the decoupling hypothesis.

### *4.4 Degrowth and ecological modernization*

Finally, whether and how we should degrow our economies is an ongoing debate. Degrowth advocates typically support resource caps and most resource cap discussion has occurred within this context. In contrast, there has been little discussion of resource caps from more mainstream ecological modernists, who have nonetheless addressed carbon caps.

Kallis (2011) defines sustainable degrowth as 'a socially sustainable and equitable reduction (and eventual stabilisation) of society's throughput' (p. 874). The degrowth movement dates from the 1970s and it is now present in activist movements and academic and policy circles (Weiss & Cattaneo, 2017). Kallis (2011) suggests that degrowth serves as a unifying keyword for a variety of different policies and initiatives that have roots in criticisms of development and the ability to decouple economic growth from resource consumption and environmental impact. Degrowth generally centers around (a) contraction of economic and material outputs in the Global North, which would allow space for (b) livelihood improvements in the Global South, entailing greater affluence and material intensity, albeit through alternative pathways to the dominant neoliberal sustainable development pathways (Hanaček et al., 2020). At least in regard to energy, Oswald et al. (2021) found that redistribution and increased equality can ensure billions of people no longer face energy poverty, and at the same time while others would need to reduce energy consumption, no one else would fall below this level.

Van den Bergh (2011) argues the degrowth literature seems to be more idealistic and utopian rather than practical. He suggests drastic societal and economic changes proposed may not in fact lead to the expected outcomes and may rather contribute to large-scale unrest and upheaval. Instead, it may be better to add new institutions and to apply concrete environmental limits, such as caps on production, to existing economic activity. Martinez-Alier et al. (2010) posit that one of the main issues with degrowth, in comparison to more mainstream movements such as sustainable development, is that it is more challenging to current political actors and that few in government or in private industries feel they could support it. Schmelzer et al. (2022) argue that planning for degrowth is a major research gap to address and that the management of resource caps are something that needs to be addressed within this context. Degrowth supporters favor caps of different kinds, because of the lack of success of the approaches mentioned above, and their support of more radical, society-changing actions (Jackson, 2009).

Most contemporary cap research has occurred within the literature on degrowth. Alexander & Gleeson (2019) suggest that diminishing resource caps are needed to degrow the material base of an economy, and may in fact lead to more efficient resource use. Cosme et al. (2017) list seven degrowth sources in a table suggesting caps, both tradable and non-tradable, on resource consumption and extraction. Typically, resource caps are presented as one of many items on a degrowth agenda, or as a component of a successful degrowth strategy (e.g. Sekulova et al., 2013). Mastini et al. (2021) also view environmental caps and bans as a degrowth strategy. Schmelzer et al. (2022) support resource caps as a more effective alternative to current market and technology-based approaches. Zoellick and Bisht (2018) cite Alcott (2010) on impact caps, and highlight them as an example of a 'sufficiency' strategy to reduce resource use often advocated for by degrowth supporters. Keyßer and Lenzen (2021) present caps and eco-taxes as an example of a degrowth policy that may lead to a shrinkage of GDP. Kallis et al. (2012) highlight that caps and other related policy options are a topic on which the degrowth and steady-state economy literature overlaps, and suggest that caps are a promising direction. Kallis and Martinez-Alier (2010) support the idea of caps as a degrowth strategy but outline many difficulties surrounding them (see Section 3). Finally, although caps have been supported in many of the articles outlined above, there is some dissonance; while most papers assume a cap-and-trade approach, many researchers who write on degrowth themes are skeptical regarding the expansion of market-based approaches (e.g. Fotopoulos, 2007, Trainer, 2014). Although resource caps using a cap-and-trade approach may entail the creation of new markets, this would be on resources that are already traded on markets. This differentiates resource caps from more problematic proposals to create markets on for instance biodiversity and ecosystems.

In contrast to degrowth, resource caps are, as noted above, absent from the ecological modernization literature. By contrast, caps on carbon and other pricing instruments are viewed as the most economically efficient tools at reducing greenhouse gas emissions (e.g. Edenhofer et al., 2015; Schmalensee & Stavins, 2017). Reasons given to support carbon caps are that they stimulate technological development and lead to a more efficient allocation of resources (Edenhofer et al., 2015). There is no research on why carbon caps are relatively mainstream among ecomodernists and resource caps are not. There are several plausible reasons. The first could be due to confidence in technology to find substitutes for scarce resources, meaning that resource scarcity could be perceived as far less immediate a threat than climate change. Second, there could simply be a lack of knowledge on the issues surrounding resource consumption compared with climate change. Third, climate change is a highly global issue with clear links between carbon emissions and climate change, whereas the impacts of resource consumption can be more localized and the links between consumption, extraction, and impact can be complex and hidden.

Resource caps are policies that bear some similarities with the EU ETS, which is a multi-nation carbon market utilizing cap-and-trade and covering many industries within the EU, and could be used as a stepping-stone to a degrowth policy agenda, or as a way of finding common ground with those who advocate alternative futures. A resource cap is arguably compatible with degrowth, zero growth, and growth approaches. However, one of the key issues with sequential and gradual policy change is that caps may be overly lenient and fail to influence strong environmental outcomes. For example, the EU ETS has been criticized for not leading to a large enough reduction in emissions, leading to unequal distribution of costs, and insufficiently driving innovation (Branger et al., 2015).

## 5. Recommendations for future research

Two main future research directions on resource caps emerge. The first relates to the theory behind resource caps and current socio-political environments. What kinds of political or institutional changes are needed for resource caps, and how will they be set and by whom? The second is how will caps work in practice? What kinds of resources, if any, should be capped, how, and where?

As resource caps would require extensive programs in terms of setting, monitoring, and design (e.g. Kallis & Martinez-Alier, 2010), it is unclear whether current legal and policy institutions would be suitable for implementing resource caps, although existing carbon caps such as the EU ETS could be used as an initial point of reference.

As outlined cogently by Kallis and Martinez-Alier (2010), some of the most important questions surrounding resource caps pertain to how they would be set and by whom. As with any other government policy, the power relations of access and control will determine the effectiveness of resource caps not only in mitigating environmental problems but also balancing social and economic equity (e.g. Bryant, 1998; Ribot & Peluso, 2003). As many government policies are vulnerable to co-option to some degree by powerful actors, or to (mis)use by authoritarian regimes, the question is whether resource caps are any more likely than other policies to be enlisted in this way. As seen in Section 4, it is possible resource caps may be more likely than some other policies to fall afoul of these issues. For example, large corporations could stand to make large profits by controlling resources restricted by caps (Stratford, 2020).

Although Kallis and Martinez-Alier (2010) state that most researchers take democracy as a given and are strongly against supporting authoritarian regimes in any form, there is room for a realpolitik argument, as has occurred with calls for stronger action on climate change, in favor of resource caps. There are nations such as China that have high levels of environmental impact and show no signs of transitioning to become more democratic or allow more citizen participation in governance in the near future. Researchers may need to engage with such states and proceed with research on sustainability policies regardless of the risk of co-option. Without strong cooperation, including with less democratic regimes, it will be difficult to design and implement constraints on global resource use.

There are clear issues with such a realpolitik approach. The first is the history of environmental policies being enacted by powerful elite groups and being used to justify control or displacement of minority groups, particularly Indigenous communities (e.g. Benjaminsen & Bryceson, 2012; Scheidel & Work, 2018).

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As caps would limit mining, this seems less likely to occur than with other environmental policies, but it could be used as an excuse to justify government crackdown on local peoples in precarious mining situations, such as artisanal cobalt miners in the Congo. Additionally, it is questionable whether many authoritarian regimes would have a legitimate desire to pursue environmentally friendly policies, even if economically viable, if they come at economic or political cost. As authoritarian regimes rely on concessions or rent-sharing with powerful actors to maintain power (Gandhi & Przeworski, 2006), environmental policies that reduce the ability of the state to extract rent from resources would be against the political interest of most authoritarian regimes.

The second main recommendation is to investigate how caps could work in practice. As outlined above, there has been no research investigating what kinds of resources should be capped and where they could be capped, and even less experimentation with resource caps outside of those on carbon and renewable resources. Research has been at a very abstract level. Caps could target specific resources such as molybdenum, of concern to Henckens et al. (2019), or be aimed at some form of aggregate material flows, as suggested by Lettenmeier et al. (2014) in their work on rationing. The former approach may be more promising, as it would be prohibitively difficult to track, monitor, and regulate overall economy-wide material use given current monitoring abilities. In contrast, it has been shown with various degrees of success that we can cap or apply permit systems to specific substances such as water and carbon emissions.

However, deciding what resources could be worth capping is difficult. First, the work on resource criticality by Thomas Graedel and others is a promising starting point for selecting a resource as it covers environmental impact and risks to resource supply that would cover both economic and security concerns (e.g. Graedel et al., 2015). But there could be other considerations such as the cultural importance or use of resources. Second, capping specific resources, while simpler than an aggregate-material cap, is still highly complicated, as resources such as indium, neodymium, and gold can be embedded at a low value in a myriad of products and flows are complicated and can criss-cross borders (e.g. Thiébaud et al., 2018).

As a policy approach that would require extensive planning, monitoring, and regulation, resource caps would not be effective for all states or places. There are still questions surrounding what kinds of governmental, political, and social conditions would render a cap feasible, and whether there are existing institutional and legal frameworks in place, or whether such frameworks are possible, that would allow caps to occur on scales beyond the state or supranational. Caps would have to function as intended, and would need popular or legislative support to be maintained, to avoid the fate of the Australian carbon cap-and-trade scheme that was removed upon a change of government in 2013. The presence of international treaties similar to the UNFCCC may help maintain such policies. It would also need to make economic sense due to the cost of maintaining a monitoring program, and would need to lead to justifiably significant environmental or social outcomes. Kallis and Martinez-Alier (2010) suggest that there has been a move away from regulatory caps in other domains such as water policy toward more flexible, local policies, and there would need to be clear reasons for undergoing the cost and time of implementing caps at a given scale, and monitoring implementation, rather than attempting a more flexible regulatory approach.

Further research is needed into the design characteristics of resource caps. For example, what kind of redistribution or permit schemes would work best? The literature on carbon caps would provide insight here. At this stage research on resource caps is too theoretical and undeveloped to transfer easily to practical implementation. Hence the purpose of this review to summarize and outline a path forward for future research in this area, as the economic and political constraints to caps have emerged as significant.

## 6. Conclusion

Increasingly unsustainable rates of resource extraction and consumption are driving innovative scientific and policy responses to a growing global crisis, anchored by the need to address climatic change, carbon emissions, and biodiversity loss. Resource caps are a promising approach to reducing consumption of specific resources, including critical minerals, that have a high-environmental impact and could be included as an option in discussions about addressing overreach in the social metabolism and resource scarcity. As the literature suggests, decoupling economic growth from adverse environmental impacts and material consumption appears impossible in practice with current levels of technology and energy sources (Trainer, 2007).

Therefore, resource caps and other 'strong' approaches to sustainable consumption and production should be considered. Caps on resources have been called for by supporters of degrowth, who aim at wasteful, highly carbon intense, and unequal economies. Pursuing further research on caps can help bridge the gap in planning for degrowth. This review has found, however, that resource caps are not incompatible with the agendas of those that support or are neutral regarding the 'weaker' sustainability implied by continued economic growth and more conscientious use of the earth's resources combined with a modernist belief in the power of technological advances.

However, there are several issues surrounding resource caps that need to be addressed. Resource caps could easily lend themselves toward technocratic approaches, as seen in the EU ETS, despite researchers calling for caps to be developed through post-normal science. Although this review suggested that caps could be implemented through the adoption of techniques from the social metabolic literature, this could further risk technocracy. While resource caps are most likely to be implemented at a national or regional level, doing so without broader international collaboration could risk geopolitical ramifications, particularly if caps are implemented further up the supply chain such as at the point of extraction. Furthermore, it is still unclear what kinds of institutional or government structures are needed to maintain and implement caps, following the urgent and still partial regimes directing global carbon emissions legislated by recent UNFCCC agreements. It is also unclear whether resource caps run a larger risk of authoritarian co-option than other policies, with potential appropriation by corporate interests or authoritarian states. More generally, the key questions of how, and even if, resource caps can work in practice remain unanswered.

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