

Future CO₂ emissions from shipping: four-scenarios using a multi-level perspective – a proposed methodology

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Abstract. Previous work by Pettit et al (2017) drew on Socio-technical Transitions Theory (STT) to contextualise recent developments in the technological and operational eco-efficiency of ships which may ameliorate sustainability issues in shipping. Within STT the Multi-Level Perspective (MLP) is a framework used to explain the permeation of innovations into society (Geels, 2014). The framework has three levels: Landscape; Regime and Niche. In order to develop a better understanding of changes that may take place in the future, this paper uses the MLP to assess the broad range of challenges facing the shipping industry with respect to future CO₂ emissions at each of the three levels. The framework is applied to four scenarios for global shipping in order to understand the potential range of outcomes for CO₂ emissions. The four scenarios are: ‘Business as Usual’; ‘Managed Transition’; ‘Chaotic Transition’; and ‘Managed Degrowth’. It is contended that changes in the shipping industry alone are unlikely to lead to large-scale changes in its CO₂ emissions. Under ‘Business as Usual’ conditions, CO₂ emissions will continue to rise as the changes required at all three levels, but primarily at the regime level, will have limited impact. Under the other three scenarios, it is suggested that there is room for optimism that CO₂ emissions will decline over time.

Introduction

Previous work by Pettit et al (2017) drew on Socio-technical Transitions Theory (STT) to contextualise recent developments in the technological and operational eco-efficiency of ships which may ameliorate sustainability issues in shipping. Within STT the Multi-Level Perspective (MLP) is a framework which is used to describe and explain the permeation of innovations into society (Geels, 2014). The framework has three levels: Landscape; Regime and Niche. The ‘Landscape’ level pertains to over-arching trends and contextualising factors such as economic growth, long-run price movements, trade policies, and environmental conditions. The ‘Regime’ level is understood to be a dynamically stable ensemble of organisations, technologies, laws, social and employment policies practices, and related matters that essentially describe the world as we know it. Finally, the ‘Niche’ level pertains to protected spaces away from mainstream governance wherein new technologies or social practices can be experimentally initiated, and potentially nurtured to the point where they displace an incumbent regime.

As shipping is fundamentally a derived demand which arises out of, but also enables, the spatial separation of production and consumption the industry is a ‘hostage to fortune’ as it responds to, rather than leading, overarching economic changes. This has meant that historically shipping has been a facilitator of global economic growth, with CO₂ emissions growing steadily as the shipping industry has grown to meet need. Thus, in order to develop a better understanding of changes that may take place in the future, this paper uses the MLP to assess the broad range of challenges facing the shipping industry with respect to future CO₂ emissions at each of the three levels. The framework is applied to four scenarios with regards to the future of global shipping in order to understand the potential range of outcomes for CO₂ emissions. The four scenarios are: ‘Business as Usual’; ‘Managed Transition’; ‘Chaotic Transition’; and ‘Managed Degrowth’.

Socio-technical transitions, multi-level perspectives and futures thinking

The study of socio-technical transitions is concerned with understanding how, and to what effect, technologies permeate society. Theoretically, socio-technical transitions draws from multiple antecedents in evolutionary

economics, the sociology of innovation, and institutional theory with a concern for understanding the relationship between technological innovation and economic growth. An initial impetus was long wave theory, as developed by the Russian economist Kondratiev, and elaborated more formally by Schumpeter. In a defining statement on the emerging research agenda for socio-technical transitions, Köhler et al. (2017) put emphasis on the multi-dimensional, multi-actor, and co-evolutionary character of change in which outcomes are uncertain. Hence while technologies may still be at the core of explaining change, socio-technical transitions scholars integrate an understanding of the contested (and hence political) character of change processes. The so-called Multi-Level Perspective (MLP) is one framework adopted in transitions studies (Geels, 2014), although others are also used (Smith et al., 2010). STT thereby seeks to embrace the complexity of social reality, but also to simplify that reality in order to make it susceptible to rigorous analysis. Under the MLP framework the initial understanding was that change and stability could be identified within a hierarchy of three levels.

The landscape level pertains to over-arching trends and contextualising factors such as economic growth, long-run price movements, trade policies, and environmental conditions. In principle landscape-level factors change relatively slowly and are systemic in impact. One example of a long-term landscape change may be the development of the 'One-Belt One-Road' (OBOR) initiative being promoted by China. This initiative seeks to further integrate Asia, Europe, and Africa through two interlinked components: the Silk Road Economic Belt, a land-based transport network connecting China to Europe and the Middle East through Central Asia and Russia, and a twenty first century Maritime Silk Road connecting ports in Asia, Africa and Europe. Development under this US\$ 1.2 trillion project includes roads, rails, airports, seaports, energy pipelines, and other core projects in the region. The OBOR strategy (if successful) has far-reaching implications for the future volume and balance of shipping trade around the world. Although it will take many years to become a reality, the consequences may be profound for shipping if significant volumes of cargo are transferred from sea to alternative land routes (Ferdinand, 2016). With its claim to boost support for green and low-carbon development, there will be an impact on carbon emissions, and evaluating its contribution towards a low-carbon economy.

The regime level is understood as a dynamically stable ensemble of organisations, technologies, laws, social practices and related matters that essentially describe the world as we know it. Change certainly happens at this level, but with multiple feedback loops that act to dampen the pace and degree of change. In general then, regimes are self-perpetuating ensembles, conditioned from above by the factors at the landscape level. Emergent niches largely fail to displace incumbent regime structures, but sometimes do. Examples of 'regime' level organisations include the IMO and other representative organisations such as Tanker Owners (ITOPF), port representative organisations (ESPO), Labour organisations (ITF), ship owners, ship operators, naval architects, shipbuilders and suppliers, flag states, finance and investment organisations, and the customers of the shipping sector (both on the supply side and the demand side).

Finally, the niche level pertains to protected spaces away from the mainstream wherein new technologies or social practices can be experimentally initiated, and potentially nurtured to the point at which the niche can displace an incumbent regime. Niches tend to be conceptualised as emerging rapidly, but often disappearing equally rapidly. Niches may therefore expand and effectively displace one regime with another, as in the way that steam displaced sail in shipping (Geels, 2002). Such changes, or transitions, have the potential to follow several pathways variously combining new entrants with incumbents as defined by, for example, Berggren et al., (2015) and Hess (2013). Examples of 'niche' activities in the realm of shipping include: the development of battery electric power and other supplementary power through the use of sail and solar assistance technology, the further development of slow steaming and cold ironing, the 'greening' of port activities, and 'virtual' port arrival. The three levels are illustrated in Figure 1.

Transitions studies are concerned with future sustainability, but they tend to be empirically grounded in historical research. While transition pathways may be viewed as conceptual experiments to contemplate possible futures, in practice the tendency has been to explore observed empirical outcomes of the near or more distant past. Scenarios are an established method of contemplating possible futures, which may or may not be desired, with a view to informing corporate strategy or government policy (Dixon, 2011).

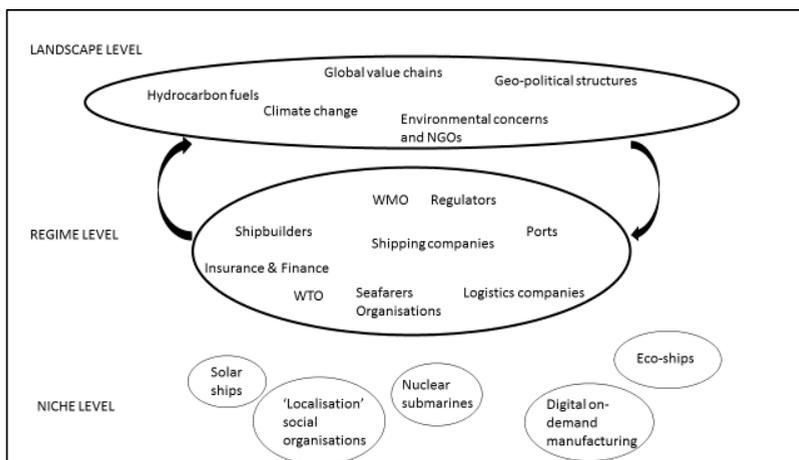
Socio-technical transitions and shipping

The shipping industry is in a state of transition as it adjusts to increasingly strict emissions standards promoted primarily at the regime level. There is an increasing awareness of shipping's contribution to global emissions of greenhouse gases; a low-carbon economy is identified as one of the Sustainable Development Goals from the UN. Landscape changes are also relevant however, as, for example, China's OBOR strategy will have profound implications in supporting this transition and acting upon long-term environmental change.

Discussion on the future of carbon emissions from shipping, and the future of the sector more generally, tend to be constrained by a focus on economic imperatives and rationality, along with an incremental view of future change possibilities. Shipping can be powerfully symbolic (and symbolic of the projection of power) as is the case

with aircraft carriers for example, and as was the case with the vessels of the Cunard line. More generally, the future of shipping is not reducible to the economics of moving materials and products across the seas of the globe, but is also likely to be profoundly shaped by national and international policy measures, by shifts in geo-political possibilities, by technological and operational innovation, and indeed by climate change. Socio-technical transitions theory provides a framework in which the multi-dimensional and co-evolutionary aspects of change can be systematically captured. Shipping is more than just ships. Shipping is an increasingly complex system of inter-related parts including ports, land transport systems, satellites, and related matters but also extending all the way to consumption practices and norms that, for example, regard importing finished products from distant countries to be an acceptable means of achieving aspirational material lifestyles. In other words, cultural norms and expectations over things like work, employment, consumption, and globalisation are powerfully influential on existing shipping practices. Similarly, emergent expectations around sustainability in its broadest sense will come to bear on shipping.

Figure 1. The multi-level perspective of socio-technical transitions applied to shipping.



Source: Pettit et al, 2017

In principle then, STT can inform the construction of alternative scenarios, which can then be used to generate illustrative outcomes (see McDowall, 2014; Angheloiu et al., 2017). Historical studies may also be used to validate the assumptions underpinning expectations with regards to the pace and direction of transitions that might emerge from the scenarios (McDowall, 2016). Nonetheless, a concern with validation of this type is that unforeseen or unprecedented events may occur, and these may be precisely the ‘regime changing’ events that could have a significant impact on future outcomes. Scenarios are inevitably also concerned with multiple agents of possible change, and of interactions between agents.

Scenarios and future shipping carbon emissions

It is recognised in the transitions literature that there are competing visions for the future (Geels et al., 2015). In this paper we seek an explicit exploration of those competing visions through the use of scenarios as they apply to carbon emissions from shipping. Four scenarios are defined in this paper and summarised in Table 1. Two of the scenarios represent managed change within plausible or broadly accepted limits, albeit with rather different outcomes. These first two scenarios are ‘business as usual’ and ‘managed transition’. The remaining two scenarios are much more dramatic in terms of impact but are included to illustrate alternative pathways to very low carbon emission outcomes: chaotic transition and managed degrowth.

It can be seen that the scenarios are described in terms of STT theory, with distinct characteristics at landscape, regime, and niche levels. The three main levels thus are interactive, with for example developments at landscape level pressuring change at regime and niche levels, but with say regime innovations having repercussions at landscape level. In this regard the scenarios can be understood as unfolding processes rather than simple destination states of a system.

Business as usual

The business as usual scenario does not mean ‘no change’. Rather, it represents the idea that current trends will continue, and future changes of significance are readily able to be forecast. Hence it is anticipated in this scenario that global trade broadly continues, and that shipping continues to be a significant component of this trade. The regime in this respect continues to be self-regulating, while landscape-level pressures are not so profound as to demand drastic and enduring shifts in shipping. Technological innovation and ‘normal’ competition will continue to drive down carbon emissions per vessel or per tonne moved, but such efficiencies will be largely negated by continued growth in the overall volume of shipping. Thus, while shipping may continue to be considered to be environmentally friendly, as the level of emissions per unit moved will be low due to scale economies, the overall emissions burden created by shipping will remain a significant and increasing part of global emissions.

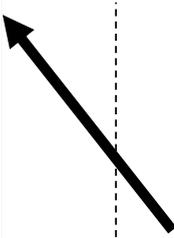
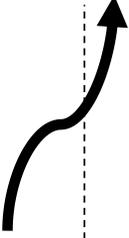
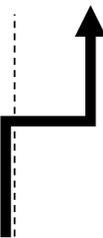
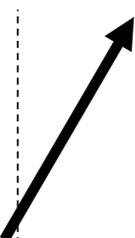
Managed transition

The idea behind the managed transition scenario is the beneficial restructuring of economies and the technologies embedded in many aspects of life can deliver more sustainable production and consumption. A likely outcome is an emphasis on the circular economy operating at a local or national scale, and in combination with reduced material and energy intensity in economies (i.e. a decoupling of economic growth from material and energy consumption) there is a concomitant reduction in the volume of shipping even as the activity becomes more efficient in carbon emissions terms. Hence the overall result is an accelerating process whereby carbon emissions are reduced, before stabilizing around a new regime structure. Carbon emissions in total are thus substantially below the business as usual scenario, but still end up higher than the latter two scenarios.

Chaotic transition

In ‘futures’ thinking, it is rarely acknowledged that there may be catastrophic change, by which we mean change so abrupt and profound that it destroys existing social structures. Yet historically many societies have witnessed cataclysmic collapse, and certainly in the contemporary world the prospect of nuclear Armageddon cannot be discounted. There are also current examples where individual countries have come close to collapse through the use of extreme measures to subdue a local population resulting in the largescale movement of people either within a country as ‘internally displaced people or out of a country as ‘refugees’. The consequent economic scenario for such countries is poor and will ultimately impact on a countries ability to trade internationally. The collapse of the global economic order does seem unimaginable, but a process of competitive disengagement is relatively easy to envisage – as is evident by the isolationism pursued by the USA since the 2016 election (see, for example, BBC, 2018a). Another current example is the political confrontation between Russia and the western bloc concerning cyber security and espionage (see, for example, BBC, 2018b). Chaotic transition may result from unbearable landscape pressures manifest across societies and their economies, including shipping. The resultant outcome would be a collapse in carbon emissions.

Table 1. Scenarios for shipping using the MLP framework

Baseline Features	Oil and other prices; GDP change; geopolitical events; trade and liberalisation policies; environmental changes; infrastructure developments; population size and structure; consumption behaviours and practices	Industry and companies; governance; representative organisations; social norms; legal structures and enforcement; markets; supply and demand; investment	Technological and material innovations; organisational, procedural and social (grassroots) innovations; micro-markets and specialist applications.	Current level of CO₂ emissions
Scenario	Landscape Level	Regime Level	Niche Level	CO₂ trajectory
Business as usual (Hickman and Banister, 2007; Meadows et al, 1972)	Steady global GDP growth; stable commodity prices; robust global trade agreements; reductions in CO ₂ emissions in other sectors creating 'headroom' for shipping; conservative planning with no major transformation in the way transport is performed	Growth in shipping volumes; ship numbers; and in stock turnover rate. Further cost reductions achieved. Latent cyclical over-capacity remains. Actions of NGOs, IMO, investors, owners, etc. remain similar to today.	Some niche technology developments in specialist applications e.g. battery electric ferries; fuel cell ferries in harbours; solar panels and other renewables on some vessels.	
Managed transition (Geels, 2014; Geels et al., 2014)	Green growth strategy; de-couple resource consumption from GDP; reduced trade volumes in food; materials and products; policy targets towards the circular economy; global consensus politics.	Stronger regulation and policy towards shipping and ports; CO ₂ trading in shipping; Eventual decline in scale of the sector; concentration of ownership; new routes open up.	Strong encouragement of emergent technologies and fuel efficiency measures; new operational practices e.g. on-board additive manufacturing in transit.	
Chaotic transition (Tainter, 1988)	Environmental, economic and political collapse on a global scale; return to isolationism; widespread loan defaults; severe climate change emerging; food and other shortages.	Collapse of intermediary governance organisations; widespread business failure; loss of investor confidence	No new technologies or operational practices; some innovation in 'scavenging' and retrofit of parts; some new uses found for vessels	
Managed degrowth (Kallis, 2011)	Chronic material shortages; abandoned use of GDP as a measure of progress; strong regulation at international level to ensure equity of outcomes; rapid restoration of some environmental degradation.	Sequential deconstruction of main fleets; industry atrophy; break-up of large MNCs. Strong role of regulatory agencies such as IMO in transition phase. Substantial pre-negotiation period before actions taken.	Potentially significant innovation in alternatives to shipping; reduced material consumption in any case; possible growth in passenger liner niches as alternative to flying.	

Managed degrowth

An emergent prescription is for managed degrowth, whereby the deliberate aim is to reduce an economy in scale. It is argued that landscape pressures can only be resolved by drastic de-consumption, and a rejection of materialism as a measure of economic success. In order to prevent chaos, and to protect the vulnerable (in a society; in a country) this process of change must be managed. Some aspects of shipping may benefit from these changes, for example with a renewed emphasis on leisure time perhaps the ‘cruise’ line sector will prosper more. Broadly, a combination of technological innovation and dramatic reductions in trade volumes will reduce carbon emissions to a very low level. One of the principal issues in this scenario is the balance between managed degrowth in developed economies and the need for economic growth in developing countries. Developing nations are likely to see degrowth as a first world problem, and such an approach will require a careful balancing or rebalancing of the global economy.

Scenario Modelling

In order to understand what the outcomes of the scenarios presented above might be, a methodology for modelling such changes is presented below. The modelling methodology will be explored in more detail in future analysis.

In terms of methodology there are variables identified that can influence outcomes at the regime level, such as economic growth rates or shifts in petroleum prices changing the economies of scale and hence economic structure of the shipping industry. Such relationships may vary according to the type of shipping concerned (bulker, container, etc.) or indeed by the route, by source or by destination. The initial step is to understand how far the landscape descriptors explain the current structure and recent past changes in the global shipping industry as the most aggregated levels of analysis. This ‘top down’ approach can then be cascaded into types of shipping, specific commodity flows, etc., as desired. Given that we anticipate landscape level changes to be the most important determinant of the future of shipping, the focus is on how this overarching level influences the regime and the niche levels.

Note also, however, that the more extreme scenarios are less amenable to traditional econometric modelling. There may be distinct de-coupling of outcomes from variables that were previously explanatory. Indeed a central thrust of much policy with regards to sustainability is to de-couple economic growth from material and energy consumption. In shipping terms, this may mean de-coupling growth in shipping from economic growth. However, the scenarios should enable a statement on the likely character of the shipping industry under each scenario case, and for the implications of that character in terms of carbon emissions to be expressed. In so far as shifts in the industry at regime or niche level occur, there may thus be outcomes in terms of changes at a landscape level (i.e. as measured by CO₂ emissions to the atmosphere).

The arrows in Table 1 are indicative of expected outcomes under the scenarios. However the landscape, regime and niche descriptors are also, in effect, expected outcomes or internally consistent constructs of different ‘worlds’ of shipping under different conditions. A key question in these outcomes is that of time. In other words, at what rate will change occur or, alternatively, by what date would an outcome be observed? Generally scenarios are useful for long-term projections of the order of 20 to 30 years maybe. The chaotic transition and managed degrowth scenarios both imply drastic change over a short period of time consistent with virtually halting carbon emissions. The time required for the managed transition scenario is the least predictable, but elements are known. For example, it should be possible to forecast a rate of technology penetration and shift in shipping volumes consistent with a steady decline in global shipping emissions. Equally, the business as usual scenario largely implies a continuation of current trends: more efficient shipping offset by volume growth leading to gradual growth in total emissions.

Proposed methodology

In order to model what is described above, a multi-step approach to estimate and forecast shipping CO₂ emissions at the three levels of the MLP model, and to determine the effect of external and internal economic variables on shipping emissions structural change, under the four scenarios, is proposed.

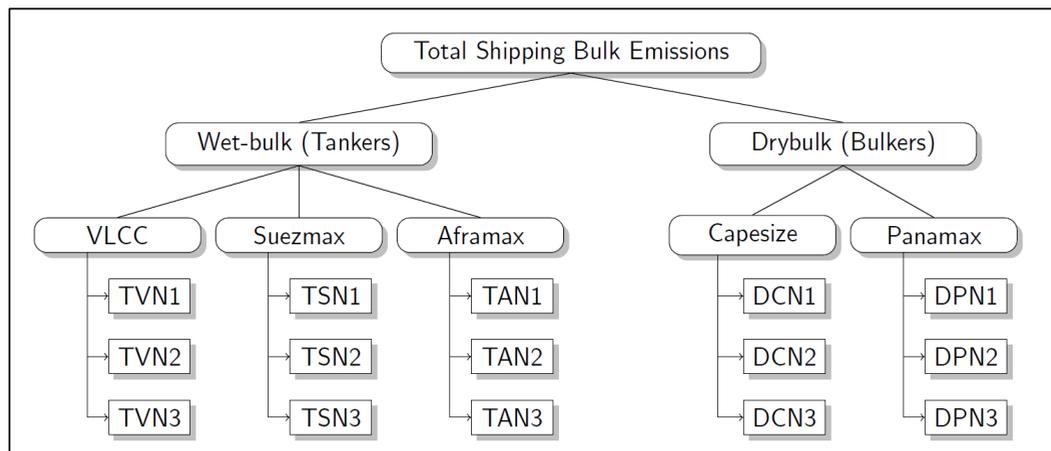
First, an annual time series for shipping emissions in tonnes will be structured using a fuel-based (top-down) approach, as described in Pettit et al 2017, and using equation (1):

$$SE_{annual_t} = \sum_{i=1}^n \left(\frac{Bf_{i,daily}}{AC_i} \times ST_{i,annual_t} \times EF_{CO_2} \right)_{annual_t} \quad (1)$$

where SE_{annual_t} is annual shipping emissions at time t , $Bf_{i,daily}$ is daily burned fuel for trade i , AC_i is average transported cargo for trade i and at any given day, $ST_{i,annual_t}$ is annual seaborne trade for trade i at time t , EF_{CO_2} is the CO₂ emission factor, and n is total number of trades (e.g. tankers and dry bulk). The result is a figure for total CO₂ emissions for the shipping industry in the form of an annual time series.

The structured time series of shipping emissions in equation (1) is then used to determine the significance of the MLP framework in explaining historical structural changes in shipping emissions and second, to determine the drivers of shipping emissions under the proposed four scenarios. Thus, shipping emissions data is disaggregated, and hierarchically structured in the form of a top-down approach by landscape, regime and niche, as depicted in Figure 2.

Figure 2. Hierarchical structure of bulk shipping emissions categorised according to landscape, regime and niche levels within the MLP



In the hierarchical structure shown in Figure 2, a structured time series of shipping emissions estimated by equation (1) donate the completely aggregated level “Total Shipping Bulk Emissions” as level 0. This level is then further disaggregated to lower levels: “Wet-bulk (Tankers)” and “Drybulk (Bulkers)” as level 1, “VLCC”, “Suezmax”, “Aframax”, “Capesize” and “Panamax” as level 2 and the most disaggregated level, by vessel type, as level 3. Consequently, time-series data aggregated at level 0 represents estimated shipping emissions at the landscape-level of the MLP model, data disaggregated at levels 1 and 2 represents changes in shipping emissions at the regime-level and data disaggregated at level 3 represents developments in shipping emissions at the Niche-level. Thus, a 3-level hierarchy structure to study structural changes in shipping emissions at the three-levels of the MLP framework is proposed. At level 3 in Figure 2, T, V, S, A, D, C, P and N represent Tankers, VLCC, Suezmax, Aframax, Capesize, Panamax and Niche. For example, TVN1 refers to emissions from a VLCC tanker that is categorised in this study as Niche 1 (e.g. modern tanker), TVN2 as Niche 2 (e.g. old tanker), (other categories would cover short-haul and long-haul trades as appropriate).

Second, a multilevel model is suggested to estimate the macroeconomic and microeconomic drivers of structure change in shipping emissions under the assumptions of the MLP framework. Finally, the estimated assumptions are adjusted according to the four scenarios and used for forecasting shipping emissions for the next 20 – 30 years. To this end, we implement a vector autoregression (VAR) model that has proven to be useful for capturing and forecasting the dynamic behaviour between economic variables. The VAR model is used to analyse, at a multilevel within the MLP framework, the dynamic interaction between exogenous and endogenous economic variables. Our bivariate VAR(p) model equation has the form:

$$Y_t = C + A_1 Y_{t-1} + A_2 Y_{t-2} + \dots + A_p Y_{t-p} + \varepsilon_t, \quad t = 1, 2, \dots, T \tag{2}$$

where $Y_t = (y_{1,t}, y_{2,t}, \dots, y_{n,t})'$ donate an $(n \times 1)$ vector of time series variables, A_i are $(n \times n)$ coefficient matrices and ε_t is an $(n \times 1)$ unobserved zero mean white noise vector process with time invariant covariance matrix Σ .

The overall outcome of this modelling process will therefore be a disaggregation of CO₂ emissions from shipping across the range of shipping types at the three MLP levels and across the four scenarios over a medium-term time horizon.

Conclusions

It is contended that changes in the shipping industry alone are unlikely to lead to large-scale changes in its CO₂ emissions. Under 'Business as Usual' conditions, CO₂ emissions will continue to rise as the changes required at all three levels, but primarily at the regime level, will have some impact. However, the overall large-scale changes required will not be significant enough to lead to overall carbon emissions reductions and are therefore unlikely to have a significant impact on the overall carbon burden (see, for example, Jonkeren et al, 2009). Under the other three scenarios, it is suggested that there is room for optimism that CO₂ emissions will decline over time. In the 'Managed Transition' scenario, de-coupling resource consumption from GDP, greater global political consensus, stronger regulation and policy towards shipping, and encouragement for emergent technologies are likely to lead to a net decline in CO₂ emissions (Geels et al, 2015). In the 'Chaotic Transition' scenario, which was first proposed by Meadows (1970) in the context of global resource depletion, environmental, economic and political systems collapse at a global scale. As a consequence, this would bring about a return to isolationism, and widespread business failure, with little or no innovation which would in turn result in significant CO₂ emissions reductions as there would be significantly less need for shipping (Tainter, 1988). Finally, in the 'Managed Degrowth' scenario, global material shortages, stronger regulation at an international level, and innovation in alternatives to shipping would lead to a rapid decline in CO₂ emissions before a steady state at a lower level occurs (Kallis, 2011).

The technologies and operational innovations that could reduce the environmental burdens of shipping, while useful, do not represent the socio-technical system 'regime' shifts that the international maritime sector requires in order to contribute to reduced CO₂ emissions, which would enhance sustainability. It is the underlying 'landscape' shifts in production and consumption that are likely to bring about a reduction in the demand for shipping, and which will be more significant over the longer term.

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