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Human agency in the Anthropocene

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Abstract

The human species has been recognized as a new force that has pushed the Earth's system into a new geological epoch referred to as the Anthropocene. This human influence was not conscious, however, but an unintended effect of the consumption of fossil-fuels over the last 150 years. Do we, humans, have the agency to deliberately influence the fate of our species and the planet we inhabit? The rational choice paradigm that dominated social sciences in the 20th Century, and has heavily influenced the conceptualization of human societies in global human-environmental system modelling in the early 21st Century, suggests a very limited view of human agency. Humans seen as rational agents, coordinated through market forces, have only a very weak influence on the system rules. In this article we explore alternative concepts of human agency that emphasize its collective and strategic dimensions as well as we ask how human agency is distributed within the society. We also explore the concept of social structure as a manifestation of, and a constraint on, human agency. We discuss the implications for conceptualization of human agency in integrated assessment modelling efforts.

Key words: Human agency; Anthropocene; integrated assessment models; socio-metabolic agent classes

Introduction

The Sustainable Development Goals and the Paris Agreement set very ambitious goals that, if taken seriously, would result in a rapid transformation of human-environmental interactions and decarbonization of the global socio-economic system (United Nations 2015a; United Nations 2015b). What the agreements do not specify, however, is how the transformation should be achieved and who the transformation agents would be. In most modern scientific assessment of global human-environmental interactions, including Integrated Assessment Models (IAMs), alternative futures do not evolve from the behavior of the population in the simulated region or market, but are externally chosen by the research teams (e.g. Moss et al. 2010). The human agency that can be broadly understood as the capacity of individual and collective actors to change the course of events or the outcome of processes (Pattberg and Stripple 2008) is only weakly represented in the commonly used global system models. For example, Integrated Assessment Models are not capable of modelling abrupt changes and tipping points in both natural and human systems (e.g. van Vuuren et al. 2012) that may imply severe and non-linear consequences for the Earth system as a whole (Lenton et al. 2008). There is, however, a relatively rich body of literature in social sciences, primarily in political science and institutional theory, that conceptualizes human agency in the governance of social-ecological systems (e.g. Ostrom 2005; Kashwan et al. 2018) and in Earth system governance (e.g. Biermann et al. 2012; Biermann et al. 2016). The aim of this paper is to assess the representation of human agency in Earth system science and integrated assessment modelling efforts and to examine how the rich body of literature on human agency in social sciences could be used to improve the modelling efforts.

The cornerstones of social sciences are built on the tension between agency and structure in social reproduction - the force of self-determination versus the embeddedness of social institutions (Dobres and Robb 2000). Just as bio-physical laws determine the coupling between chemical and mechanical processes, social structures, including norms and institutions, impose constraints on the shaping of human interactions (North 1990); they specify what people may, must, or must not do under particular circumstances and impose costs for non-compliance (Ostrom 2005). Social institutions also have a function in expressing common or social interest and in channeling human behavior into what is socially desired (Coleman 1990). Unlike bio-physical laws, however, social institutions are man-made structures and they are constantly being transformed by human action. In general, the smaller the social entity the less durable it is. The size, scale, and time-frame of the social entity pushes it towards a durable structure and stability (Fuchs 2001). Numerous authors have contributed to this long and fruitful debate on micro- and macro-level social structures and interactions within social sciences. However, very little of that knowledge has so far been applied by the global environmental change modelling community. To give an example, the IPCC Report on Mitigation of Climate Change underlines the role of institutional, legal, and cultural barriers that constrain the low-carbon technology uptake and behavioral change. However, the diffusion of alternative values, institutions, and even technologies are not incorporated in the modelling results (Edenhofer et al. 2014). Little is known about the potential for scaling-up of social innovations, let alone the possible carbon emission reductions they could drive if applied on a larger scale. How quickly would such innovations diffuse into virtual and face-to-face social networks, and what would the agency of different actors, and groups of actors, be in such a diffusion process? The purpose of this work is to analyze how social theory could be better integrated into the global environmental change assessment community, and how relevant social theory could be incorporated in modeling efforts.

The paper is structured as follows. We start by reviewing how human agency has been incorporated within Earth system science and integrated modelling efforts so far. We then move to the exploration of the concept of human agency and social structure and review the relevant social stratification theories. We propose how the concept of human agency could be incorporated in global human-environmental system models, and finally we conclude.

Human agency in Earth system science and integrated assessment modelling

The recognition of the human species as the driving force of modern global environmental challenges, occurring at the end of the 20th Century, brought a new perspective to environmental and Earth system sciences. Lubchenco (1998) called directly for the integration of the human dimensions of global environmental changes with the physical-chemical-biological dimensions. In this context, Crutzen (2006) proposed the distinction of the Anthropocene as a new geological epoch, where the human species becomes a force outcompeting natural processes. As one possible framework to assess human agency in the Anthropocene, Schellnhuber (1999) developed the notion of “Earth System” analysis for global environmental management in which the human force has been conceptualized as a “global subject”. The global subject is a real but abstract force that represents the collective action of humanity as a self-conscious force that has conquered the planet. The global subject manifests itself, for instance, by adopting international protocols for climate protection.

The conceptualization of the human species as the global subject has been applied in Integrated Assessment Models (IAMs). IAMs refer to tools assessing strategies to address climate change and they aim to describe the complex relations between environmental, social and economic factors that determine future climate change and the effects of climate policy (van Vuuren et al. 2011). IAMs have been valuable means to set out potential pathways to

mitigate climate change and, importantly, have been used in the IPCC's assessments of climate change mitigation (Clarke et al. 2014). However, the development of Integrated Assessment Models (IAMs) coincides in time with the supremacy of the rational choice paradigm. Rational choice theory emphasizes the voluntary nature of human action and the influence of such actions on decisions, assuming human beings act on the basis of rational calculations of benefits and costs (Burns 1994). According to this paradigm, rationality is a feature of individual actors and the world can be explained in terms of interactions of atomic entities. Humans are rational beings motivated by self-interest and consciously evaluate alternative courses of action. Markets are seen as the mechanisms linking the micro and macro levels and allow the combination of the concrete actions of individuals, e.g. buyers and sellers (Jaeger et al. 2001). The rational choice paradigm is reflected in welfare maximization assumptions underpinning the development of computable general equilibrium (CGE) models that are widespread in IAMs. CGE models are computer-based simulations which use a system of equations that describe the whole world economy and their sectoral interactions. The analysis of scenarios in CGE models compares a business-as-usual equilibrium with the changes introduced by one or several policies and environmental shocks — e.g. a carbon tax or emissions trading scheme under several climate scenarios — which generates a new equilibrium (Babatunde et al. 2017). It is important to understand that the policy shock in such models is introduced externally; it does not evolve from the model and does not consider the dynamics behind the agency of different actors and groups of actors. In fact, human societies in CGE models are only reflected in aggregated population numbers by world region. The institutional settings within the human societies operate are given and cannot be endogenously changed. CGE models place a strong emphasis on the market as a solution to all kinds of problems including environmental and social issues (Scricciu 2007). Furthermore, state-of-the-art IAMs model aggregate datasets of sub-continental size. For instance, the IAM known as REMIND considers just 11 world regions, while the energy component of IMAGE

considers only 26. The order of magnitude of the population of each of these regions is between 287M and 680M inhabitants (ADVANCE, 2017). Similarly, in the global land use allocation model MAgPIE, the food energy demand for ten types of food energy categories (cereals, rice, vegetable oils, pulses, roots and tubers, sugar, ruminant meat, non-ruminant meat, and milk) in ten world regions differentiated in the model is determined exogenously by population size and income growth, assuming that, for example, higher income is related to a higher demand for meat and milk (Popp et al. 2010). The impacts of changing lifestyles and the implications of demand-side solutions can be explored only manually by varying the underlying assumptions.

In context of the definition of human agency used above, IAMs reflect an agency of a rational consumer who decides on the choice of an optimal action having access to perfect information about the alternatives. By analyzing energy, land use, and their implications on global emissions (e.g. van Vuuren, Batlle Bayer, et al. 2012; Hibbard et al. 2010) IAMs can compute an economic setup to maximize welfare functions. Nevertheless, the welfare functions do not cover the diversity of human preferences. Complex distinctions of qualitative aspects, such as networks or influencers that can drive these processes, do not exist.

This drawback has been noted by the IAM community and attempts have been made to integrate human agency related behaviour towards the political economy, social behavioural and interaction patterns (Riahi et al. 2017), or regimes of effort sharing (van den Berg et al. 2019) have been made. Some models also consider inequality and a diversity of consumption patterns (Hasegawa et al. 2015; McCollum et al. 2018). However, these approaches are still driven by exogenous quantifications and are unable to sufficiently inspect dynamics of human agency. Although IAMs are able to design pathways combining multiple strategies to achieve the 1.5 °C target of the Paris Agreement, which include human agency related actions such as

lifestyle changes (Vuuren et al. 2018), many questions remain. For example, how can human agency be triggered to achieve the lifestyle changes, at an individual level, necessary to achieve the 1.5 °C target? Also, how can the necessary institutional dynamics be brought into play? So far, these aspects are rarely considered in IAMs.

Novel and promising modelling approaches to incorporate human agency are being developed in complex network science (Borgatti et al. 2009) and social-ecological system modelling (Pérez, Janssen, and Anderies 2016). Complex networks usually consist of a set of nodes representing individual agents or representative aggregations thereof (such as business parties, geographical regions or countries) which are connected by different types of linkages, such as business relations, diplomatic ties, or even acquaintance and friendship (Newman 2018). This type of framework has been developed in the past, and applied successfully to describe heterogeneous datasets from the social sciences, and to establish conceptual models for socio-economic and socio-ecological dynamics (Filatova et al. 2013). Nevertheless, most of such models are still based on theoretical assumptions with weak links to empirical data. A closer link with empirical data has so far only been achieved at case study level, focusing on particular local socio-environmental phenomena such as fishery or water management with agents representing local resource users or managers (e.g. Suwarno et al. 2018; Troost and Berger 2015). The questions driving this work are: (i) how can similar models be conceptualized in order to represent the whole world Earth system of human societies and their bio-physical environment (Donges et al. 2018) and (ii) how can they be linked with empirical data?

The concept of human agency in social sciences

Dellas et al. (2011) refer to agency in the governance of the Earth system as the capacity to act in the face of earth system transformation or to produce effects that ultimately shape

natural processes. Agency in Earth system governance may be considered as contributing to problem solving, or alternatively it could include the negative consequences of the authority to act. Lister (2003) and Coulthard (2012), in their research on agency related to environmental and citizenship problems, distinguish two dimensions: (i) ‘everyday agency’ being the daily decision-making around how to make ends meet, and ‘strategic agency’ involving long-term planning and strategies; and (ii) ‘personal agency’ which reflects individual choices and ‘political and citizenship agency’ which is related to the capacity of people to affect the wider change (Lister 2003). Personal agency varies significantly across human individuals. However, there are powerful examples of social protests and movements demonstrating that even individually disempowered people can have a strong voice if they act collectively (Kashwan 2016). In the context of natural resources and environmental management, there are empirical examples of self-organized local and regional communities and grassroots movements crafting new institutions that limit the control of national authorities (García-López 2018; Dang 2018). To give an example, civil society groups in Mexico managed to shape the REDD+ policies to protect the rights of agrarian communities (Kashwan 2017a). In this context, Bandura (2006) proposes the differentiation of individual, proxy and collective agency (2006: 165). Individual agency refers to situations in which people bring their influence to bear through their own actions. This varies substantially from person to person with respect to individual freedom to act and the consequences of action. Individual agency is influenced by a whole set of socio-economic characteristics including gender, age, education, religion, social, economic and political capital. In many cultures, the individual agency of women is limited, for example, by inheritance law or by informal norms restricting their mobility or educational opportunities (Otto et al. 2017). However, individual agency also varies with an individual’s ability to change the system rules. For example, very wealthy or influential people might find it easier to set new market trends or influence public decision-making processes than those with fewer resources (Otto et al. 2019). Proxy, or

socially mediated agency refers to situations in which individuals have no direct control over conditions that affect their lives, but they influence others who have the resources, knowledge, and means to act on their behalf to secure the outcome they desire. Collective agency refers to situations in which individuals pool their knowledge, skills, and resources, and act in concert to shape their future (Bandura 2006: 165). These dimensions of agency are visualized in Figure 1.

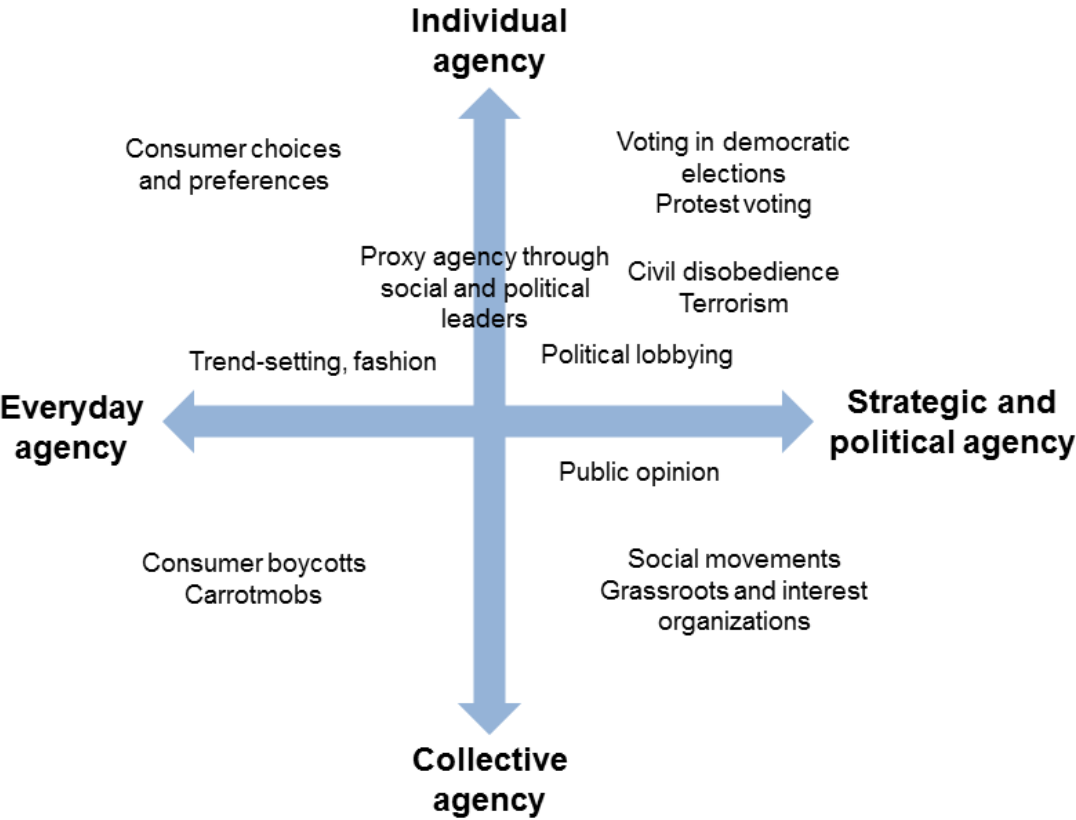


Figure 1: Agency dimensions. Adapted from Lister (2004) and Coulthard (2012) with empirical examples of social phenomena

The dominant view of human agency in Earth system science and integrated modeling approaches has so far focused on the left upper corner of Fig. 1, i.e. on the everyday agency of individual human agents. This would correspond to, for example, modelling the effects of food consumption on land use patterns (e.g. Popp et al. 2010). Interestingly, although opinion

formation and election models are well advanced in game theory (e.g. Penn 2009; Ding et al. 2010), they have not yet been applied to the formation of international environmental policy in IAMs. At the same time the recent so-called protest voting show that a small fraction of voters can push public policy down a radically different pathway. Some studies link the protest voting and rising populism with increasing inequalities and the political and social exclusion of the poor and underprivileged (Becker, Fetzer, and Novy 2017). In some cases, radical policy changes might also be achieved by individual acts of civil disobedience and, in a destructive manner, by terrorist attacks. Civil disobedience represents the peaceful breaking of unjust or unethical laws and is a technique of resistance and protest whose purpose is to achieve social or political change by drawing attention to problems and influencing public opinion. Terrorism is defined as an act of violence for the purpose of intimidating or coercing a government or civilian population.

Furthermore, radical policy changes and social tipping points can emerge due to changes in the collective behavior and preferences. The term ‘tipping point’ “refers to a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system” (Lenton et al. 2008), hence the mere existence of tipping points implies that small perturbations created by parts of such a system can push the whole system into a different development trajectory. Examples of tipping-like phenomena in socio-economic systems include financial crises, but could also include the spread of new social values, pro-environmental behavior, social movements, and technological innovations (Steffen et al. 2018). To give an example, social movements and grassroots organizations played an important role in the German energy transition that was initiated in 2011 as a reaction to the nuclear disaster in Fukushima in Japan. It was, however, preceded by about 30 years of environmental activism (Hake et al. 2015). Finally, tipping-like phenomena can also be achieved by consumer boycotts and carromob movements. Consumer boycotts coupled with environmental NGO campaigns led, in Europe, to changes in the animal welfare regulations

and the implementation of fair trade schemes (Belk et al. 2005). Carrotmobs refer to consumers collectively swarming a specific store to purchase its goods in order to reward corporate socially responsible behavior (Hoffmann and Hutter 2012).

At the same time, cultural values and the ethical interpretation of behavior might vary in some respects across different countries and world regions and will lead to different manifestations of agency. Cultural values provide a strong filter of the actions perceived as good or responsible, as well as the consequences of violating norms (Belk et al. 2005). In the climate change context, some authors link the public acceptance of climate policy instruments to the belief and value systems in place, and the perceptions of the environment (Otto-Banaszak et al. 2011).

The manifestation of human agency: The layers of social structure

Biermann and Siebenhüner (2009) propose a distinction between actors and agents in Earth system governance. Actors are the individuals, organizations, and networks that participate in the decision-making processes. Agents are those actors who have the ability to prescribe behaviour. The collective prescriptions and constraints on human behaviour are usually referred to as the social structure (Granovetter 1985; Dobres and Robb 2000). The social structure is composed of the the rule system that constitutes the “grammar” for social action that is used by the actors to structure and regulate their transactions with one another in defined situations or spheres of activity. The complex and multidimensional normative network is not given, but is a product of human action; “human agents continually form and reform social rule systems” (Burns and Flam 1986: 26). The social rule system can also be framed as social institutions that are involved in political, economic, and social interactions (North 1991). Similarly, Elinor Ostrom defines institutions as “the prescriptions that humans use to organize all forms of repetitive and structured interactions. Individuals interacting

within rule-structured situations face choices regarding the actions and strategies they take, leading to consequences for themselves and for others” (Ostrom 2005: 3). Social norms are shared understandings of actions and define which actions are obligatory, permitted, and forbidden (Crawford and Ostrom 1995). Social order is only possible insofar as participants have common values and they share an understanding of their common interests and goals (King 2009). Williamson (1998) proposes differentiating different informal institutions such as norms, beliefs and traditions, and formal institutions that comprise formal and written codes of conduct.

The process of shaping of the social rule system formation is not always fully conscious and intended. Lloyd (1988: 10) points out that a social structure is emerging from intended and unintended consequences of individual action and patterned mass behavior over time “Once such structures emerge, they feedback on the actions” (Sztompka 1991: 49). For Giddens (1984) human action occurs as a continuous flow of conduct and he proposed turning the static notion of structure into the dynamic category of structuration to describe the human collective conduct. Human history is created by intentional activities but it is not an intended project; it persistently eludes efforts to bring it under conscious direction (Giddens 1984: 27). As pointed out by Sztompka (1994), Giddens, embodies human agency in the everyday conduct of common people who are often distant from reformist intentions but are still involved in shaping and reshaping human societies. This process of the formation of social structure takes place over time; the system which individuals follow today have been produced and developed over a long period. “Through their transactions social groups and communities maintain and extend rule systems into the future” (Burns and Flam 1987: 29).

Another element of the social structure that is identified by several authors corresponds to the network of human relationships that, just like the shapes in geometry, can take different forms

and configurations (Simmel 1971). The network of relationships among the social agents is also referred to as governance structures, or sometimes as organizations. North (1990: 73) defines organizations as “purposive entities designed by their creators to maximize wealth, income, or other objectives defined by the opportunities afforded by the institutional structure of the society.” Williamson (1998), focusing on the types of contracts, distinguishes three basic types of governance structures: markets, firms, and hybrids. In markets, transaction partners are autonomous; in firms, partners are inter-dependent and integrated into an internal organization. Hybrids are intermediate forms in which contract partners are bilaterally dependent but to a large degree maintain autonomy (Williamson 1996: 95-98). Studying communication networks and social group structures allows us to distinguish more social network relationship patterns (Sztompka 2002: 138).

Finally, the social structure is also shaped and influenced by large material objects such as infrastructure and other technological and industrial structures, that some authors call the technosphere (Spaargaren 1997: 78). Herrmann-Pillath (2018) defines the technosphere as the encompassing aggregate of all artificial objects in opposition to the natural world, and more specifically, establishes the systemic separateness of the technosphere relative to the biosphere. Just as social norms impose on one hand certain constraints on human behavior, however, on the other hand, structure the human interactions and also provide certain opportunities, the technosphere can be viewed as a humanly designed constructs that provide certain opportunities as well as they limit certain choices of individuals operating at different geographical and time scales.

The system is fully interconnected, and the social structure layers are interrelated. The slow changing layers of social structure impose constraints on the layers that change more quickly. The faster changing layers of social structure, however, are also able to change the slow

slayers through feedback mechanisms (c.f. Williamson 2000). Human agency is manifested through the maintenance, reproduction and modifications in the social structure layers (Burns 1994). Interestingly, infrastructure objects in the technosphere layer show a similar order of change as the informal and formal institutions, and thus might constrain the social change in the faster changing levels. Thus artefacts become co-carriers of agency (Herrmann-Pillath 2018). Nevertheless, sharp brakes from the established procedures rarely happen. Such defining moments are an exception to the rule and usually emerge from massive discontents such as civil wars, revolutions, or financial crises (Williamson 1998). Institutions can also lock the society into a path-dependence (Beddoe et al. 2009). The capacity to undergo a radical restructuring, however, is a unique feature distinguishing social systems from organic or mechanical ones. Restructuring the social structure is a product of human agency and is grounded in the interaction between structures and human actions that produces change in a system's given form, structure or state (Archer 1988: xxii). However, the transition of institutions is frequently driven by crises (Beddoe et al. 2009).

Burns (1994: 215-216) introduces the notion of 'windows of opportunity' that are very relevant for analyzing social transformations. Interactive situations lacking social equilibria, which typically occur after catastrophes and other shocks, usually give rise to uncertainty, unpredictability, and confusion, and motivate actors to try, individually or collectively, to restructure the situation. In such restructuring activities, actors typically engage in reflective processes and make "choices about choice" and participate in meta-games (Burns et al. 1993). The actors may structure and restructure their preferences, outcomes, and outcome structures, and occasionally also the entire decision and game systems in which they participate. Through such structuring activity, human agents also create, maintain and change institutions and collective or organized agents such as movements, the state, market and bureaucratic organizations (Burns and Dietz 1992; Burns 1994: 215-216).

Transformations are the moments in history when the meta choices - “choices about choices” are made. The outcomes of such choices and the new type of system depend largely on the agents that get involved in the collective process of designing the new system. This process could be exclusive and incorporate only a narrow group of decision-makers as frequently happens in “quiet” transitions to authoritarian regimes. Alternatively, they can be more open and include representatives of various social groups, as happened in the political and economic transformation in Eastern Europe. Taking this example, Burns (1994) proposes that transformations are a co-evolutionary process sometimes driven by contradicting actors’ interests. Transformations might entail shifts in core societal organizing principles and systems of rules. As a result, agents with vested interests may struggle to maintain established systems or to limit the changes within them. Other agents act openly or covertly to modify or transform the system. Table 1 summarizes the above discussion and tries to link the social structure layers to the dominant type of human agency that can be used to transform them.

Even in periods of radical change, however, the actors never start from scratch. They cannot choose a completely new system and they always depart from the ongoing social order in which they are embedded. The future evolves from practical activities, experiments, learning, conflict and struggle (Burns 1994: 216). A similar point of view is presented by evolutionary institutional economists, in which transformations are seen not as a simple replacement of old institutions by new ones, but as a recombination and reworking of old and new elements and groups of actors (e.g. Stark 1996; Bromley 2000).

Table 1: The layers of social structure, the dominant type of agency and the order of change (following Williamson 1998).

Structure layer	Sub-components	The dominant type of human agency	The order of change
Institutional	Informal rules: norms, religion, tradition, customs	Collective and strategic	30 to over 100 years
	Formal rules: constitutions, written codes of conduct, judiciary, property rights	Collective and citizenship	10 to 50 years
Organizational	Governance structures	Proxy and strategic	5 to 10 years
	Organizations	Proxy, strategic	5 to 10 years
	Networks	Proxy, individual, everyday	Continuous
Technosphere	Infrastructure	Proxy, strategic	10-50 years
	Technology	Proxy, individual and everyday	Continuous

Distribution of human agency: Differentiating socio-metabolic agent classes

Following the rational choice paradigm could lead us to a conclusion that the society is a sum of individuals (Burns 1994) and that any forms of agency should be equally distributed among the individuals in the society. Such an approach is typical for integrated assessment models in

which human systems are usually separated into population and economic sectors. The parameters that describe population are usually mainly population number, and economic production determines the use of resources and pollution emissions in the model (e.g. van Vuuren et al. 2012).

It is, however, enough to observe the world to know that such assumptions are very simplistic. People's resource use and pollution emissions differ according to income, place of abode, type of occupation, and possessions. Moreover, their goals and interests, and the likelihood of them being fulfilled also differ. There are powerful individuals and groups in society who successfully strive for their interests, and there are individuals and groups who, despite struggling, never achieve their objectives. There are also masses of individuals who just strive to make ends meet. The questions are what types of agents or organizations can be incorporated in the models and what sort of agency do they have? Is there a need for a new social class theory taking access to energy and related carbon emissions as the base of social stratification?

Most social differentiation theories follow either the Marxist distinction between physical and capital endowments or the Weberian approach which differentiates classes through inequalities in ownership and income (Kozyr-Kowalski 1992: 53). Some class theorists also highlight the development stages and inequalities across different countries and world-regions (Offe 1992: 122). One more dimension that has not been discussed so far by social differentiation theories is the socio-metabolic profile of social classes, which constitutes the common ground for social and natural sciences. Social metabolism refers to the material flows in human societies and the way societies organize their exchanges of energy and materials with the environment (Fischer-Kowalski 1997; Martinez-Alier 2009). Social classes can be differentiated based on their metabolic profiles (Martinez-Alier 2009). The use of

energy by human beings can be divided into two main categories. The first one refers to the endosomatic use of energy as food, and the second one refers to the exosomatic use of energy as fuel for cooking and heating, and as power for the artefacts and machines produced by human society. Thus one person a day must eat the equivalent of 1,500 to 2,500 kcal to sustain their life functions, which is equivalent to about 10 MJ (megajoules) of energy per day or 3.65 GJ per year (Martinez-Alier 2009). This amount varies only slightly among human beings. A rich person physically cannot eat much more, and even poorer individuals need the equivalent energy in the form of food to survive. Dietary composition and the amount of waste produced, however, will differ across the social strata. Nevertheless, there are still people suffering from hunger, unable to meet their basic needs.

The exosomatic energy use varies to a greater degree. The poorest social groups, who have no permanent access to electricity in their homes, who obtain energy for cooking and heating from the combustion of biomass products, who use overcrowded buses and trains to travel, use in total about 10 GJ of energy per person per year (Martinez-Alier 2009) and constitute the lowest, socio-metabolic underclass. A more detailed picture can be derived by comparing the carbon footprint of different socio-economic groups. Personal CO₂ emissions are released directly in fuel combustion processes in vehicles, airplanes, heating and cooking appliances, and indirectly through electricity use and consumption of products that generated emissions in the upstream production processes. The authors include CO₂ emissions from energy used directly in homes (for space heating, lighting, etc.), for personal transportation (including personal vehicles and passenger aviation), and from the energy embedded in the production of goods consumed. Kümmel (2011) proposes the term “energy slaves” to describe the exosomatic energy use from fossil fuels by modern human society. On average, the daily energy consumption of a human being is equivalent to the men power of 15 people.

Inhabitants of the most energy intensive Western Societies (i.e. the U.S.) consume, per person, the equivalent of the work of 92 people every day.

The results from UK households show that CO₂ emissions are strongly income, but also location, dependent. The highest emissions can be generated by people living in suburbs, mostly in detached houses, and having two or more cars. Emissions of such households equated to about 26 CO₂ tonnes in 2004. This amount was 64% higher than the emissions of the group with lowest emissions of 16 CO₂, which comprised mostly of older and single person urban households as well as the unemployed living mostly in urban areas (Druckman and Jackson 2009). UK household emissions can be compared with emissions from households located in less developed countries. For example, household emissions in Malaysia, as in the UK, are strongly dependent on income and location. However, Malaysian households with the lowest emissions were found in villages as well as in low-income urban squatter settlements. The urban squatter settlement households emitted on average 10.18 CO₂ tonnes. The village households emitted on average 9.58 CO₂ tonnes per year. Households with the highest CO₂ emissions were located in high cost housing areas and they were responsible on average for 20.14 CO₂ tonnes per year (Majid, Moeinzadeh, and Tifwa 2014).

On the other end of the social ladder, there are super-rich hyper-mobile individuals with multiple spacious residences, and whose live-styles are characterized by conspicuous consumption patterns. They are less than 1% of global population and their consumption related greenhouse gas emissions could be over 170 times higher than the world's poorest 10% (Oxfam 2015). They can be characterized by extremely high levels of all types of agency. The influence and roles of many super-rich in the world of politics, media, culture, business and industry are often inter-related. In contrast to the super-rich in pre-industrial societies they have almost unlimited mobility, owning properties in different counties, with

their homes being guarded and fortified. They have the ability to switch countries of residence, taking the advantage of ‘non domiciled’ tax status, i.e. being the national of a certain country while not actually living there (Paris 2013). Table 2 presents a first attempt to stratify the global population according to their socio-metabolic profiles that is based on disaggregated data on consumption related carbon emissions (Oxfam 2015; Otto et al. 2019). The proportions in Table 2 are striking. The top 10% of the global population is responsible for almost 50% of global consumption related greenhouse gas emissions. The wealthiest 0.54% of the human population is responsible for more lifestyle carbon emissions than the poorest 50% (Otto et al. 2019).

Table 2: Socio-metabolic class differentiation (based on: Oxfam 2015; Otto et al. 2019)

	Percent of global population	Percent of life-style CO₂ emissions	The level of human agency
Socio-metabolic underclass	20%	2.5%	Extremely low
Socio-metabolic energy poor class	30%	7.5%	Low
Socio-metabolic lower class	30%	22%	Moderate level of collective agency
Socio-metabolic middle class	10%	19%	Moderate to high
Socio-metabolic upper class	9.5%	35.4%	Very high
Super-rich	0.54%	13.6%	Extremely high

Energy use, as well as carbon dioxide emission, can also be used to analyze the socio-metabolic profile of economic sectors, companies and other organizations. From 1854 to 2010 12.5% of all industrial carbon pollution was produced by just five companies – Chevron, ExxonMobil, British Petroleum, Shell and Conoco Philipps (Union of Concerned Scientists 2018). To give an example from a different sector – in 2015 Saint-Gobain, a French multinational building materials manufacturer emitted 9.5 million metric tonnes CO₂e (Carbon Disclosure Project 2016: 22). For a comparison, emissions from industrial processes in France in 2013 equated to 17.6 million tonnes CO₂e (General Directorate for Sustainable Development 2016: 25) (GTM 2018).

The socio-metabolic profile of social classes, nations, and organizations can be directly linked with their agency in the Earth system. The global socio-metabolic underclass is obviously characterized by a very low degree of agency. There are rare exceptions of mass protests initiated by the poorest social groups that can collectively influence formal institutions and change their governance (Kashwan 2017b). However, these people are mostly occupied with making ends meet and have low organizational capabilities. In contrast, the global socio-metabolic upper classes are those who are characterized by a high level of individual agency as well as having the organizational capabilities to actively exercise their agency. Due to their resource incentive life-style they also have the moral obligation to be the agents of a transformation in global sustainability.

Improving the representation of human agency in integrated assessment modelling

In this section we ask how the above conceptual discussion could be summarized into guidelines improving the operationalization of human agency in Earth system science and integrated assessment modelling. In order to incorporate the different aspects of human agency as discussed in the previous sections, there is a need to introduce agents with

heterogeneous goals, opinions and preferences into the models. The agents should be able to form networks that represent their mutual interrelationships and interactions between them. These system interaction rules should ideally refer to the social structure layers differentiated in Tab. 1, forming a nested hierarchical embeddedness of each agent.

Conceptual models, that incorporate the above requirements have been successfully developed and studied in the recent past. Their core properties might thus form a proper basis for extending IAMs to include heterogeneous agency on the level of (representative) individuals. Such models have been utilized to study opinion, and the associated consensus-formation specifically under the assumption of heterogeneous agents. Most of these works are based on the voter model in which agents exchange discrete (sets of) opinions in order to reach some consensus on a given (possibly abstract) topic or problem (Clifford and Sudbury 1973; Holley and Liggett 1975). Acknowledging that in its standard version the voter model considers all agents to have identical agency, extensions have been based on social impact theory (Latane 1981) that specifically include heterogeneous relationships between single actors or groups (Nowak et al., 1990). Such extended models generally account for proximities between agents in some abstract space of personal relationships which is commonly modeled by assigning agents unique values of persuasiveness and supportiveness, describing their agency with respect to influencing as well as supporting others. While being of generic nature such classes of models can be easily modified to account for various kinds of processes related to social behavior, such as social learning (Kohring 1996) or leadership (Holyst et al. 2001), which are again directly related to the notions of (heterogeneous distributions of) human agency. Certain models include additional layers of complexity by also accounting for the heterogeneous distribution of different group sizes (Sznajd-Weron 2005) and certain majorities within those groups (Galam 2002) when determining criteria for consensus in opinion dynamics.

One particular model of general cultural dynamics that has attracted great interest in the social science community, and that should be highlighted here, is the so-called Axelrod model (Axelrod 1997). In its core, it accounts for two commonly observed tendencies in large groups of individuals or aggregations thereof: social influence (i.e. agency) and homophily (a process that dynamically influences each individual's agency over time). The Axelrod-model not only specifically accounts for heterogeneity in the different agents but also (and to some degree unintuitively) allows emerging cultural diversity to be modeled in its convergent state. In general, such flexible approaches allow to incorporate individual human agency in terms of the different ties an agent might have with others (Emirbayer and Goodwin 1994; Granovetter 1977). Additionally, each tie can be associated with different strengths, thus also incorporating heterogeneity in the human agency (Castellano, Fortunato, and Loreto 2009). Network modeling approaches further allow us to explicitly resolve the associated social structure (as well as the temporal evolution thereof) through an evaluation of the overall topology of the network on the meso- or macroscale (Costa, Rodrigues, and Villas Boas 2007).

A necessary step in operationalizing human agency in IAMs includes differentiating global socio-metabolic agent classes with heterogeneous metabolic profiles linking them with the material and energy flows in the bio-physical environment as well as heterogeneous social profiles that specify their preferences, opinions, and positions in social networks. Such efforts could be linked to the emerging research on downscaling planetary boundaries (Häyhä et al. 2016) as well as the established research on differentiating social milieus (e.g. Bauer and Gaskell 1999). Some authors also propose model co-development, together with citizens and citizen groups (Figueres et al. 2017). Some authors also recommend abandoning the search for one gold-standard model, and instead explore future pathways based on a multitude of

different concepts and representations of people and human agency. For example, Donges et al. (2018) proposes a modelling framework allowing incorporation of large sets of different models and concepts, in a standardized form, in order to assess and compare different future trajectories.

Conclusions

The Anthropocene has emerged unintentionally as a side effect of the industrialization of human societies (Crutzen 2006). There are only a few examples of the human ability to internally interact with planetary geological forces, with the Montreal Protocol being the most often referred to example (Velders et al. 2007). At the same time historical examples show that there are instances of rapid transitions in societies (Bunker and Alban 1997). Achieving policy challenges as outlined in the Sustainable Development Goals require a certain degree of societal transformation. The concept of agency is central to implementing transformations needed to limit global warming and achieve the SDGs. Most of the IAMs that dominate the scientific assessments of global environmental changes do not include a representation of human societies that would have a capacity to undertake system transformations. At the same time, there is a relatively rich social science theory that can be used to improve the operationalization of human agency in integrated assessment modelling efforts.

In this paper we show that human agency can actively shape the world-Earth system (c.f. Donges et al. 2018) through interventions at different layers of social structure. Human agency, however, is not evenly distributed across all human individuals and social groups. We postulate a differentiation of socio-metabolic agent classes that could be integrated into integrated assessment modelling efforts. More socio-economic sub-national and sub-population group data is needed for this purpose (c.f. Otto et al. 2015). Social institutions for sustainable management of global, regional, and local ecosystems, however, do not generally

evolve spontaneously, but have to be consciously designed and implemented by the resource users (Gatzweiler and Hagedorn 2002; Kluvankova-Oravska et al. 2009). Each social transformation contains a disruptive component that implies a destruction of existing patterns of social interaction and institutional structures, and creation and emergence of new patterns and structures. Introducing more dimensions of human agency into IAMs, and co-creating scenarios and pathways for modeling exercises together with citizens and institutions, would help break the barriers that disconnect peoples' actuality and agency with models, a discourse which has been gaining weight amongst policy makers (Figueres, 2016). This disconnection can be broken by co-developing with citizens and various resource users the elements of global human-environmental system models, and by considering the people behind the numbers and the possible ways of funneling their agency. We encourage the integrated modelling community to work more closely with social scientists as well as we encourage social scientists to explore the methods and concepts applied in natural sciences.

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References

- ADVANCE. 2017. The common Integrated Assessment Model (IAM) documentation. http://http://iamcdocumentation.eu/index.php/IAMC_wiki
- Archer, M.S. 1988. *Culture and Agency*. Cambridge: Cambridge University Press.
- Axelrod, Robert. 1997. *The Complexity of Cooperation. Agent-Based Models of Competition and Collaboration*. Princetion: Princetion University Press.
- Babatunde, Kazeem Alasinrin, Rawshan Ara Begum, and Fathin Faizah Said. 2017. "Application of Computable General Equilibrium (CGE) to Climate Change Mitigation Policy: A Systematic

- Review." *Renewable and Sustainable Energy Reviews* 78 (October): 61–71.
<https://doi.org/10.1016/j.rser.2017.04.064>.
- Bauer, Martin W., and George Gaskell. 1999. "Towards a Paradigm for Research on Social Representations." *Journal for the Theory of Social Behaviour* 29 (2): 163–86.
<https://doi.org/10.1111/1468-5914.00096>.
- Becker, Sascha O., Thiemo Fetzer, and Dennis Novy. 2017. "Who Voted for Brexit? A Comprehensive District-Level Analysis." *Economic Policy* 32 (92): 601–50.
<https://doi.org/10.1093/epolic/eix012>.
- Beddoe, Rachael, Robert Constanza, Joshua Farley, Eric Garza, Jennifer Kent, and et al. 2009. "Overcoming Systemic Roadblocks to Sustainability: The Evolutionary Redesign of Worldviews, Institutions, and Technologies." *PNAS* 106 (8): 2483–89.
- Belk, Russell, Timothy Devinney, and Giana Eckhardt. 2005. "Consumer Ethics Across Cultures." *Consumption Markets & Culture* 8 (3): 275–89.
<https://doi.org/10.1080/10253860500160411>.
- Berg, Nicole J. van den, Heleen L. van Soest, Andries F. Hof, Michel G. J. den Elzen, Detlef P. van Vuuren, Wenying Chen, Laurent Drouet, et al. 2019. "Implications of Various Effort-Sharing Approaches for National Carbon Budgets and Emission Pathways." *Climatic Change*, February. <https://doi.org/10.1007/s10584-019-02368-y>.
- Biermann, F., K. Abbott, S. Andresen, K. Bäckstrand, S. Bernstein, M. M. Betsill, H. Bulkeley, et al. 2012. "Navigating the Anthropocene: Improving Earth System Governance." *Science* 335 (6074): 1306–7. <https://doi.org/10.1126/science.1217255>.
- Biermann, F., and B. Siebenhüner. 2009. *Managers of Global Change: The Influence of International Environmental Bureaucracies*. MIT Press.
- Biermann, Frank, Xuemei Bai, Ninad Bondre, Wendy Broadgate, Chen-Tung Arthur Chen, Opha Pauline Dube, Jan Willem Erisman, et al. 2016. "Down to Earth: Contextualizing the Anthropocene." *Global Environmental Change* 39 (July): 341–50.
<https://doi.org/10.1016/j.gloenvcha.2015.11.004>.
- Borgatti, Stephen P., Ajay Mehra, Daniel J. Brass, and Giuseppe Labianca. 2009. "Network Analysis in the Social Sciences." *Science* 323 (5916): 892–95. <https://doi.org/10.1126/science.1165821>.
- Bromley, Daniel. 2000. "Most Difficult Passage: The Economic Transition in Central and Eastern Europe and the Former Soviet Union." In . Berlin.
- Bunker, B. B., and B. T. Alban. 1997. *Large Group Interventions: Engaging the Whole System for Rapid Change*. San Francisco: Jossey-Bass Publications.
- Burns, Tom R. 1994. "Two Conceptions of Human Agency: Rational Choice Theory and the Social Theory of Action." In *Agency and Structure. Reorienting Social Theory.*, Sztompka, Piotr (Ed.). Yverdon, Camberwell, Paris: Gordon and Breach Science Publishers.
- Burns, Tom R., and Thomas Dietz. 1992. "CULTURAL EVOLUTION: SOCIAL RULE SYSTEMS, SELECTION AND HUMAN AGENCY
 CULTURAL EVOLUTION: SOCIAL RULE SYSTEMS, SELECTION AND HUMAN AGENCY." *International Sociology* 7 (3): 259–83. <https://doi.org/10.1177/026858092007003001>.
- Burns, Tom R., and Helena Flam. 1986. *The Shaping of Social Organization: Social Rule System Theory and Its Applications*. London: Sage.
- Carbon Disclosure Project. 2016. "Embedding a Carbon Price into Business Strategy." https://b8f65cb373b1b7b15feb-c70d8ead6ced550b4d987d7c03fcd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/001/132/original/CDP_Carbon_Price_2016_Report.pdf?1474269757.
- Castellano, Claudio, Santo Fortunato, and Vittorio Loreto. 2009. "Statistical Physics of Social Dynamics." *Reviews of Modern Physics* 81 (2): 591–646.
<https://doi.org/10.1103/RevModPhys.81.591>.
- Clarke, Leon, K. Akimoto, M. Babiker, and et al. 2014. "Assessing Transformation Pathways." In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

- Cambridge, UK and New York, USA: Cambridge University Press.
https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter6.pdf.
- Clifford, Peter, and Aidan Sudbury. 1973. "A Model for Spatial Conflict." *Biometrika* 60 (3): 581–88.
<https://doi.org/10.1093/biomet/60.3.581>.
- Coleman, James S. 1990. "Commentary: Social Institutions and Social Theory." *American Sociological Review* 55 (3): 333–39. <https://doi.org/10.2307/2095759>.
- Costa, L. da F., F. A. Rodrigues, and P. R. Villas Boas. 2007. "Characterization of Complex Networks: A Survey of Measurements." *Advances in Physics* 59 (1): 167–242.
<https://doi.org/10.1080/00018730601170527>.
- Crawford, Sue E. S., and Elinor Ostrom. 1995. "A Grammar of Institutions." *American Political Science Review* 89 (3): 582–600. <https://doi.org/10.2307/2082975>.
- Crutzen, Paul J. 2006. "The 'Anthropocene.'" In *Earth System Science in the Anthropocene*, 13–18. Springer, Berlin, Heidelberg. https://doi.org/10.1007/3-540-26590-2_3.
- Dang, Wenqi. 2018. "How Culture Shapes Environmental Public Participation: Case Studies of China, the Netherlands, and Italy." *Journal of Chinese Governance* 0 (0): 1–23.
<https://doi.org/10.1080/23812346.2018.1443758>.
- Dellas, Eleni, Philipp Pattberg, and Michele Betsill. 2011. "Agency in Earth System Governance: Refining a Research Agenda." *International Environmental Agreements: Politics, Law and Economics* 11 (1): 85–98. <https://doi.org/10.1007/s10784-011-9147-9>.
- Ding, Fei, Yun Liu, Bo Shen, and Xia-Meng Si. 2010. "An Evolutionary Game Theory Model of Binary Opinion Formation." *Physica A: Statistical Mechanics and Its Applications* 389 (8): 1745–52.
<https://doi.org/10.1016/j.physa.2009.12.028>.
- Dobres, Marcia-Anne, and John E. Robb. 2000. *Agency in Archaeology*. London and New York: Routledge.
- Donges, Jonathan F., Jobst Heitzig, Wolfram Barfuss, and et al. 2018. "Earth System Modelling with Complex Dynamic Human Societies: The Copan: CORE World-Earth Modeling Framework." *Earth System Dynamics*. <https://doi.org/10.5194/esd-2017-126>.
- Druckman, Angela, and Tim Jackson. 2009. "The Carbon Footprint of UK Households 1990-2004: A Socio-Economically Disaggregated, Quasi-Multiregional Input-Output Model." *Ecological Economics* 68: 2066–77.
- Edenhofer, O., R. Pichs-Madruga, and Y. Sokona. 2014. *Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, USA: Cambridge University Press.
- Emirbayer, Mustafa, and Jeff Goodwin. 1994. "Network Analysis, Culture, and the Problem of Agency." *American Journal of Sociology* 99 (6): 1411–54. <https://doi.org/10.1086/230450>.
- Figueres, Christiana, Hans Joachim Schellnhuber, Gail Whiteman, Johan Rockström, Anthony Hobley, and Stefan Rahmstorf. 2017. "Three Years to Safeguard Our Climate." *Nature* 546 (7660): 593–95.
- Figures, Christina. 2016. "Plenary Talk by Ch. Figueres, Executive Secretary of the United Nations Framework Convention on Climate Change." Plenary talk at the Adaptation Futures Conference, Rotterdam, 10-13 May 2016, Amsterdam.
<https://www.youtube.com/watch?v=LOvDelpVM8w>.
- Filatova, Tatiana, Peter H. Verburg, Dawn Cassandra Parker, and Carol Ann Stannard. 2013. "Spatial Agent-Based Models for Socio-Ecological Systems: Challenges and Prospects." *Environmental Modelling & Software*, Thematic Issue on Spatial Agent-Based Models for Socio-Ecological Systems, 45 (July): 1–7. <https://doi.org/10.1016/j.envsoft.2013.03.017>.
- Fischer-Kowalski, M. 1997. "Society's Metabolism: On the Childhood and Adolescence of a Rising Conceptual Star." In *The International Handbook of Environmental Sociology*. Cheltenham, UK: Edward Elgar Publishing.
- Fuchs, Stephan. 2001. "Beyond Agency." *Sociological Theory* 19 (1): 24–40.
<https://doi.org/10.1111/0735-2751.00126>.

- Galam, S. 2002. "Minority Opinion Spreading in Random Geometry." *The European Physical Journal B - Condensed Matter and Complex Systems* 25 (4): 403–6. <https://doi.org/10.1140/epjb/e20020045>.
- García-López, Gustavo A. 2018. "Rethinking Elite Persistence in Neoliberalism: Foresters and Techno-Bureaucratic Logics in Mexico's Community Forestry." *World Development*, March. <https://doi.org/10.1016/j.worlddev.2018.03.018>.
- Gatzweiler, F.w., and K. Hagedorn. 2002. "The Evolution of Institutions in Transition." *International Journal of Agricultural Resources, Governance and Ecology* 2 (1): 37–58. <https://doi.org/10.1504/IJARGE.2002.000021>.
- General Directorate for Sustainable Development - SOeS. 2016. "Key Figures on Climate France and Worldwide. 2016 Edition." http://www.statistiques.developpement-durable.gouv.fr/fileadmin/documents/Produits_editoriaux/Publications/Reperes/2015/highlights-key-figures-climate-2016-edition.pdf.
- Giddens, Anthony. 1984. *The Constitution of Society. Outline of the Theory of Structuration*. Berkley and Los Angeles: University of California Press.
- Granovetter, Mark. 1985. "Economic Action and Social Structure: The Problem of Embeddedness." *American Journal of Sociology* 91 (3): 481–510. <https://doi.org/10.1086/228311>.
- Granovetter, Mark S. 1977. "The Strength of Weak Ties" This Paper Originated in Discussions with Harrison White, to Whom I Am Indebted for Many Suggestions and Ideas. Earlier Drafts Were Read by Ivan Chase, James Davis, William Michelson, Nancy Lee, Peter Rossi, Charles Tilly, and an Anonymous Referee; Their Criticisms Resulted in Significant Improvements." In *Social Networks*, edited by Samuel Leinhardt, 347–67. Academic Press. <https://doi.org/10.1016/B978-0-12-442450-0.50025-0>.
- GTM. 2018. "Analysis: CO2 Emissions at the World's Largest Companies Are Rising." May 2, 2018. <https://www.greentechmedia.com/articles/read/analysis-firms-with-leading-climate-strategies-have-better-stock-performanc#gs.Y6dytuE>.
- Hake, Jürgen-Friedrich, Wolfgang Fischer, Sandra Venghaus, and Christoph Weckenbrock. 2015. "The German Energiewende – History and Status Quo." *Energy, Sustainable Development of Energy, Water and Environment Systems*, 92, Part 3 (December): 532–46. <https://doi.org/10.1016/j.energy.2015.04.027>.
- Hasegawa, Tomoko, Shinichiro Fujimori, Kiyoshi Takahashi, and Toshihiko Masui. 2015. "Scenarios for the Risk of Hunger in the Twenty First Century Using Shared Socioeconomic Pathways." *Environmental Research Letters* 10 (1).
- Häyhä, Tiina, Paul L. Lucas, Detlef P. van Vuuren, Sarah E. Cornell, and Holger Hoff. 2016. "From Planetary Boundaries to National Fair Shares of the Global Safe Operating Space — How Can the Scales Be Bridged?" *Global Environmental Change* 40 (September): 60–72. <https://doi.org/10.1016/j.gloenvcha.2016.06.008>.
- Herrmann-Pillath, Carsten. 2018. "The Case for a New Discipline: Technosphere Science." *Ecological Economics* 149 (July): 212–25. <https://doi.org/10.1016/j.ecolecon.2018.03.024>.
- Hibbard, Kathy, Anthony Janetos, Detlef P. van Vuuren, Julia Pongratz, Steven K. Rose, Richard Betts, Martin Herold, and Johannes J. Feddema. 2010. "Research Priorities in Land Use and Land-Cover Change for the Earth System and Integrated Assessment Modelling." *International Journal of Climatology* 30 (13): 2118–28. <https://doi.org/10.1002/joc.2150>.
- Hoffmann, Stefan, and Katharina Hutter. 2012. "Carrotmob as a New Form of Ethical Consumption. The Nature of the Concept and Avenues for Future Research." *Journal of Consumer Policy* 35 (2): 215–36. <https://doi.org/10.1007/s10603-011-9185-2>.
- Holley, Richard A., and Thomas M. Liggett. 1975. "Ergodic Theorems for Weakly Interacting Infinite Systems and the Voter Model." *The Annals of Probability* 3 (4): 643–63.
- Holyst, Janusz A., Krzysztof Kacperski, and Frank Schweitzer. 2001. "Social Impact Models of Opinion Dynamics." In *Annual Reviews of Computational Physics IX*, Volume 9:253–73. Annual Reviews of Computational Physics, Volume 9. WORLD SCIENTIFIC. https://doi.org/10.1142/9789812811578_0005.

- Jaeger, Carlo C., Ortwin Renn, Eugene A. Rosa, and Thomas Webler. 2001. *Risk, Uncertainty, and Rational Action*. London and Sterling: Earthscan Publications Ltd.
- Kashwan, Prakash. 2016. "Inequality, Democracy, and the Environment: A Cross-National Analysis." *Ecological Economics*, no. 131: 139–51.
- . 2017a. *Democracy in the Woods. Environmental Conservation and Social Justice in India, Tanzania, and Mexico*. New York: Oxford University Press.
- . 2017b. "Inequality, Democracy, and the Environment: A Cross-National Analysis." *Ecological Economics* 131: 139–51.
- Kashwan, Prakash, Lauren M. MacLean, and Gustavo A. García-López. 2018. "Rethinking Power and Institutions in the Shadows of Neoliberalism: (An Introduction to a Special Issue of World Development)." *World Development*, May. <https://doi.org/10.1016/j.worlddev.2018.05.026>.
- King, Anthony. 2009. "Overcoming Structure and Agency. Talcott Parsons, Ludwig Wittgenstein and the Theory of Social Action." *Journal of Classical Sociology* 9 (2): 260–88.
- Kluvankova-Oravska, Tatiana, Veronika Chobotova, Lenka Slavikova, and Sonja Trifunovova. 2009. "From Government to Governance for Biodiversity: The Perspective of Central and Eastern European Transition Countries - 0f3175391c2efbd10d000000.Pdf." *Environmental Policy and Governance* 19: 186–96.
- Kohring, G. A. 1996. "Ising Models of Social Impact: The Role of Cumulative Advantage." *Journal de Physique I* 6 (2): 301–8. <https://doi.org/10.1051/jp1:1996150>.
- Kozyr-Kowalski, Stanislaw. 1992. "Economic Ownership and Partial and Combined Classes of Society. An Attempt at a Postive Critique of Post-Marxian Marxism." In *On Social Differentiation. A Contribution to the Critique of Marxis Ideology*. Poznan: Adam Mickiewicz University Press.
- Kümmel, Reiner. 2011. *The Second Law of Economics: Energy, Entropy, and the Origins of Wealth*. Springer Science & Business Media.
- Latane, Bibb. 1981. "The Psychology of Social Impact." *American Psychologist* 36 (4): 343–56.
- Lenton, T. M., H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf, and H. J. Schellnhuber. 2008. "Tipping Elements in the Earth's Climate System." *Proceedings of the National Academy of Sciences* 105 (6): 1786–93. <https://doi.org/10.1073/pnas.0705414105>.
- Lenton, Timothy M., Hermann Held, Elmar Kriegler, Jim W. Hall, Wolfgang Lucht, Stefan Rahmstorf, and Hans Joachim Schellnhuber. 2008. "Tipping Elements in the Earth's Climate System." *PNAS* 105 (6): 1786–93.
- Lloyd, C. 1988. *Explanation in Social History*. Oxford: Blackwell.
- Lubchenco, Jane. 1998. "Entering the Century of the Environment: A New Social Contract for Science." *Science* 279 (5350): 491–97. <https://doi.org/10.1126/science.279.5350.491>.
- Majid, M.R., S.N. Moeinzadeh, and H.Y. Tifwa. 2014. "Income-Carbon Footprint Relationship for Urban and Rural Households of Iskandar Malaysia." *IOP Conf. Series: Earth and Environmental Science* 18 (012164): 1–5.
- Martinez-Alier, Joan. 2009. "Social Metabolism, Ecological Distribution Conflicts, and Languages of Valuation." *Capitalism Nature Socialism* 20 (1): 58–87.
- Moss, Richard H., Jae A. Edmonds, Kathy A. Hibbard, Martin R. Manning, Steven K. Rose, and et al. 2010. "The next Generation of Scenarios for Climate Change Research and Assessment." *Nature* 463: 747–56. <https://doi.org/doi:10.1038/nature08823>.
- Newman, Mark. 2018. *Networks*. Oxford University Press.
- North, Douglass C. 1990. *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press.
- . 1991. "Institutions." *Journal of Economic Perspectives* 5 (1): 97–112. <https://doi.org/10.1257/jep.5.1.97>.
- Offe, Clauss. 1992. "The Welfare State, New Class Differentiation and Diminution of Social Conflict." In *On Social Differentiation. A Contribution to the Critique of Marxis Ideology.*, 97–130. Poznan: Adam Mickiewicz University Press.
- Ostrom, Elinor. 2005. *Understanding Institutional Diversity*. Princenton: Princeton University Press.

- Otto, Ilona M., Anne Biewald, Dim Coumou, Georg Feulner, Claudia Köhler, Thomas Nocke, Anders Blok, et al. 2015. "Socio-Economic Data for Global Environmental Change Research." *Nature Climate Change* 5: 503–6.
- Otto, Ilona M., Kyoung Mi Kim, Nika Dubrovsky, and Wolfgang Lucht. 2019. "Shift the Focus from the Super-Poor to the Super-Rich." *Nature Climate Change* 9 (2): 82–84. <https://doi.org/10.1038/s41558-019-0402-3>.
- Otto, Ilona M., Diana Reckien, Christopher P. O. Reyer, Rachel Marcus, Virginie Le Masson, Lindsey Jones, Andrew Norton, and Olivia Serdeczny. 2017. "Social Vulnerability to Climate Change: A Review of Concepts and Evidence." *Regional Environmental Change*, February. <https://doi.org/10.1007/s10113-017-1105-9>.
- Otto-Banaszak, Ilona, Piotr Matczak, Justus Wesseler, and Frank Wechsung. 2011. "Different Perceptions of Adaptation to Climate Change: A Mental Model Approach Applied to the Evidence from Expert Interviews." *Regional Environmental Change* 11 (2): 217–28. <https://doi.org/10.1007/s10113-010-0144-2>.
- Oxfam. 2015. "Extreme Carbon Inequality." Oxfam Media Briefing. Oxfam. <https://www.oxfam.org/en/research/extreme-carbon-inequality>.
- Paris, Chris. 2013. "The Homes of the Super-Rich: Multiple Residences, Hyper-Mobility and Decoupling of Prime Residential Housing in Global Cities." In *Geographies of the Super-Rich*. Cheltenham, UK; Northampton, MA, USA: Edward Elgar.
- Pattberg, Philipp, and Johannes Stripple. 2008. "Beyond the Public and Private Divide: Remapping Transnational Climate Governance in the 21st Century." *International Environmental Agreements: Politics, Law and Economics* 8 (4): 367–88. <https://doi.org/10.1007/s10784-008-9085-3>.
- Penn, Elizabeth Maggie. 2009. "A Model of Farsighted Voting." *American Journal of Political Science* 53 (1): 36–54. <https://doi.org/10.1111/j.1540-5907.2008.00356.x>.
- Pérez, Irene, Marco A. Janssen, and John M. Anderies. 2016. "Food Security in the Face of Climate Change: Adaptive Capacity of Small-Scale Social-Ecological Systems to Environmental Variability." *Global Environmental Change* 40 (September): 82–91. <https://doi.org/10.1016/j.gloenvcha.2016.07.005>.
- Popp, Alexander, Hermann Lotze-Campen, and Benjamin Bodirsky. 2010. "Food Consumption, Diet Shifts and Associated Non-CO2 Greenhouse Gases from Agricultural Production." *Global Environmental Change, Governance, Complexity and Resilience*, 20 (3): 451–62. <https://doi.org/10.1016/j.gloenvcha.2010.02.001>.
- Riahi, Keywan, Detlef P. van Vuuren, Elmar Kriegler, Jae Edmonds, Brian C. O'Neill, Shinichiro Fujimori, Nico Bauer, et al. 2017. "The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview." *Global Environmental Change* 42 (January): 153–68. <https://doi.org/10.1016/j.gloenvcha.2016.05.009>.
- Schellnhuber, H. J. 1999. "'Earth System' Analysis and the Second Copernican Revolution." *Nature* 402 (6761supp): C19–23. <https://doi.org/10.1038/35011515>.
- Scricciu, S. Serban. 2007. "The Inherent Dangers of Using Computable General Equilibrium Models as a Single Integrated Modelling Framework for Sustainability Impact Assessment. A Critical Note on Böhringer and Lüscher (2006)." *Ecological Economics* 60 (4): 678–84. <https://doi.org/10.1016/j.ecolecon.2006.09.012>.
- Simmel, Georg. 1971. *On Individuality and Social Forms. Selected Writings*. Chicago and London: The University of Chicago Press.
- Spaargaren, Gert. 1997. *The Ecological Modernization of Production and Consumption. Essays in Environmental Sociology*. Wageningen: Universtiy of Wageningen.
- Stark, David. 1996. "Recombinant Property in East European Capitalism." *American Journal of Sociology* 101 (4): 993–1027. <https://doi.org/10.1086/230786>.
- Steffen, Will, Johan Rockström, Katherine Richardson, Timothy M. Lenton, Carl Folke, Diana Liverman, Colin P. Summerhayes, et al. 2018. "Trajectories of the Earth System in the

- Anthropocene." *Proceedings of the National Academy of Sciences*, August, 201810141. <https://doi.org/10.1073/pnas.1810141115>.
- Suwarno, Aritta, Meine van Noordwijk, Hans-Peter Weikard, and Desi Suyamto. 2018. "Indonesia's Forest Conversion Moratorium Assessed with an Agent-Based Model of Land-Use Change and Ecosystem Services (LUCES)." *Mitigation and Adaptation Strategies for Global Change* 23 (2): 211–29. <https://doi.org/10.1007/s11027-016-9721-0>.
- Sznajd-Weron, Katarzyna. 2005. "Sznajd Model and Its Applications." *ArXiv:Physics/0503239*, March. <http://arxiv.org/abs/physics/0503239>.
- Sztompka, Piotr. 1991. *Society in Action. The Theory of Social Becoming*. Chicago: University of Chicago Press.
- . 1994. "Evolving Focus on Human Agency in Contemporary Social Theory." In *Agency and Structure. Reorienting Social Theory*. Yverdon, Camberwell, Paris: Gordon and Breach Science Publishers.
- . 2002. *Socjologia: Analiza Społeczeństwa*. Krakow: Znak.
- Troost, Christian, and Thomas Berger. 2015. "Dealing with Uncertainty in Agent-Based Simulation: Farm-Level Modeling of Adaptation to Climate Change in Southwest Germany." *American Journal of Agricultural Economics* 97 (3): 833–54. <https://doi.org/10.1093/ajae/aau076>.
- Union of Concerned Scientists. 2018. "Largest Producers of Industrial Carbon Emissions." May 2, 2018. https://www.ucsusa.org/global-warming/science-and-impacts/science/largest-producers-industrial-carbon-emissions.html#.Wumo_n--mUI.
- United Nations. 2015a. "Resolution Adopted by the General Assembly on 25 September 2015. Transforming Our World: The 2030 Agenda for Sustainable Development." http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E.
- . 2015b. "UN Sustainable Development Goals." United Nations. <http://www.un.org/sustainabledevelopment/sustainable-development-goals/#>.
- Velders, Guus J. M., Stephen O. Andersen, John S. Daniel, David W. Fahey, and Mack McFarland. 2007. "The Importance of the Montreal Protocol in Protecting Climate." *Proceedings of the National Academy of Sciences* 104 (12): 4814–19. <https://doi.org/10.1073/pnas.0610328104>.
- Vuuren, Detlef P. van, Laura Batlle Bayer, Clifford Chuwah, Laurens Ganzeveld, Wilco Hazeleger, Bart van der Hurk, Twan van Noije, Brian O'Neil, and Bart J. Strengers. 2012. "A Comprehensive View on Climate Change: Coupling of Earth System and Integrated Assessment Models." *Environmental Research Letters* 7: 1–10.
- Vuuren, Detlef P. van, Jason Lowe, Elke Stehfest, Laila Gohar, Andries F. Hof, Chris Hope, Rachel Warren, Malte Meinshausen, and Gian-Kasper Plattner. 2011. "How Well Do Integrated Assessment Models Simulate Climate Change?" *Climatic Change* 104 (2): 255–85. <https://doi.org/10.1007/s10584-009-9764-2>.
- Vuuren, Detlef P. van, Elke Stehfest, David E. H. J. Gernaat, Maarten van den Berg, David L. Bijl, Harmen Sytze de Boer, Vassilis Daioglou, et al. 2018. "Alternative Pathways to the 1.5 °C Target Reduce the Need for Negative Emission Technologies." *Nature Climate Change* 8 (5): 391–97. <https://doi.org/10.1038/s41558-018-0119-8>.
- Williamson, Oliver E. 1998. "Transaction Costs Economics: How It Works; Where It Is Headed." *De Economist* 146 (1): 23–58.
- . 2000. "The New Institutional Economics: Taking Stock, Looking Ahead." *Journal of Economic Literature* 38 (3): 595–613. <https://doi.org/10.1257/jel.38.3.595>.