




# COMMONSIM: Simulating the utopia of COMMONISM

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## Abstract

This research article presents an agent-based simulation hereinafter called COMMONSIM. It builds on COMMONISM, i.e. a large-scale commons-based vision for a utopian society. In this society, production and distribution of means are not coordinated via markets, exchange and money, or a central polity, but via bottom-up signalling and polycentric networks, i.e. ex ante coordination via needs. Heterogeneous agents care for each other in life groups and produce in different groups care, environmental as well as intermediate and final means to satisfy sensual-vital needs. Productive needs decide on the magnitude of activity in groups for a common interest, e.g. the production of means in a multi-sectoral artificial economy. Agents share cultural traits identified by different behaviours: a propensity for egoism, leisure, environmentalism and productivity. The narrative of this utopian society follows principles of critical psychology and sociology, complexity and evolution, the theory of commons and critical political economy. The article presents the utopia and an agent-based study of it, with emphasis on culture-dependent allocation mechanisms and their social and economic implications for agents and groups.

**Keywords** Utopia · Commons · Agent-based modelling · Critical political economy · Cultural evolution · Networks · Inclusive social-ecological provisioning

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## 1 Introduction

The formulation of utopias is usually restricted to the use of scientific prose or fiction, rendering the assessment of related uncertainties difficult. For that very reason, utopia development is a rare practice in academia, even if the demands for a social and economic alternative are high, given the presence of multiple global crises. Nevertheless, what if imaginary conceptions of society, culture, economy and politics could be experimentally tested? How could one develop such an experiment? Truly, there are obvious and manifold reasons why grand-scale radical social experiments should not be tried out in real societies. However, there is no reason why we should not run such experiments in artificial societies, simulated in computational sandboxes. Computational power has increased tremendously in the last decades, to such an extent that we are able to run multi-agent simulations at high scales and substantiate the understanding of imaginary conceptions of societies.

The utopia we aim to test addresses the question of stable cooperation in large-scale societies. We thereby recall a core research question from the field of cultural evolution and institutional and evolutionary economics, about the stability of cooperation in large-scale societies (e.g. Bowles and Gintis 2011; Boyd and Richerson 2005). While closed-form analytical approaches via evolutionary games did confirm the importance of (in)direct reciprocity (Nowak and Sigmund 2005) and altruistic punishment (Boyd et al. 2003) in small-scale groups, agent-based simulation approaches could show that under certain conditions, cooperation may also stabilise groups even at larger scales, depending e.g. on platform size, environment or the degree of institutional policing (Elsner and Heinrich 2009; Safarzynska 2013; Wäckerle et al. 2014). However, these types of models usually overemphasise the aspect of population dynamics as a central concern in the modern synthesis of evolutionary biology (see Huxley 1942; Mayr 1942). As highlighted by Pigliucci and Müller (2010), this view needs to be extended with more emphasis on environmental and structural conditions of transformational development and evolution. Cooperation does not only depend on individual behaviour in human societies, but foremost on specific historical, geographical and political conditions of social structures, such as the mode of production and the way various needs are coordinated. The latter suggests a more transformational approach to evolution (Liagouras 2013; Hanappi and Scholz-Wäckerle 2017; Scholz-Wäckerle 2023), in contrast to a generalised Darwinism, focused on variational evolution via population dynamics (Hodgson and Knudsen 2010).

In this article, we highlight the role of the commons, in particular that of the process of commoning, for stabilising cooperation in large-scale societies. However, the commons are not employed in an evolutionary game of population dynamics, but are rather embedded in a concrete utopian vision with clear social structures of coordination and a mode of production in mind. We present a novel approach for the collective development of concrete utopias via large-scale in silico experiments, operated through computational social simulations, in particular agent-based simulations. Theoretically, the utopian perspective investigated is aligned with the radical commons discourse (Ruivenkamp and Hilton 2017) and

in particular with the conception of “commonism” (Sutterlütty and Meretz 2018; 2023). This commons-based utopia highlights the complex relations between micro (the individual), meso (the commons) and macro (the society). It is, to our knowledge, the first utopian approach developing a thorough micro foundation, i.e. critical psychology (Holzkamp 1983; 2024), a clear meso conception of what a commons is and its constituent practice of commoning (de Angelis 2017) as well as a discussion of political economic processes and structures crystallising the societal level of commons in Marxian tradition. The evolving complexity of those micro-meso-macro relations and their emergent structures is the central subject of investigation in our research.

The presented agent-based model builds up a complex web of commons, composed of a multi-sectoral input–output structure. The commons do not only produce inputs for production and final life means of consumption but also care means and ecological sinks. The dynamics of COMMONSIM rest upon an *ex ante* coordination of means, in comparison to an *ex post* coordination as given by exchange via markets. The agents organise and coordinate among themselves in commons through commoning to produce different kinds of means, without the use of any money, but by mediation of needs or use values. Central to these dynamics are polycentric economic coordination and stigmergy. Polycentric economic coordination is a form of governance with multiple centres of planning and decision-making (Ostrom 2005; 2010). Self-organised planning and coordination depend upon cooperation with others and are consequently semi-autonomous (Carlisle and Gruby 2019). Otherwise, stigmergy is a form of indirect and decentralised communication via signs, which was first discovered by biologist Pierre-Paul Grassé (1959), studying termites. Human indirect communication is conscious and much more complex, but these signs also adapt to complex cooperation in local environments. The idea of distributed, self-organised and foremost democratic planning can be used to transform current platform structures of modern capitalism in stigmergic terms (von Redecker 2020). Communist inclusive provisioning integrates feedback and signalling mechanisms into production and coordination by local—in contrast to complete—information updating about the state of wellbeing of agents and groups. Furthermore, decisions depend on voluntary and inclusive cooperation of the commons. There is no central institution enforcing a grand plan, and therefore, the dominant form of power is social power resting on the “capacity to mobilize people for cooperative, voluntary collective actions” (Wright 2010). An additional characteristic of COMMONSIM is the introduction of diverse group cultures along different traits. Agents carry certain traits with them, following broadly “modernism”, “traditionalism” and “environmentalism”. A mix of all traits is found in a residual category of “random agents”. The network of commons depends on cooperative partner relations between the sectors of production; culture is significant for the choice of the cooperative partner and consequently for the allocation of means. We assume that not all cultural traits make agents act altruistically through their production groups; they may also discriminate agents of other cultures by banning them from group-level participation or refrain from cooperative partner relations with groups of other cultures. With a set of computational simulation experiments, we test the robustness of production and care on behalf of within- and between-group selection processes. Therefore,

stabilising cooperation in this large-scale and complex artificial society constitutes our main research questions:

What is the role of inclusive provisioning within and between cultures for stable social and economic reproduction in a large-scale web of commons? Then, how can cooperation be stabilised by particular institutional mechanisms in the absence of inclusive provisioning?

The principle of inclusive provisioning governs relations between micro, meso and macro, making it a core mechanism for stabilising the reproduction of the commons on a macro scale. We approach these mechanisms with an agent-based network model of commonism. To simulate such commons-based complex systems, several authors suggest a disaggregated simulation approach (Janssen & Ostrom 2006; 2007; Ostrom and Basurto 2011) which can be achieved with agent-based modelling (ABM). ABM is frequently used for computational social simulations and has several advantages compared to equation-based modelling (Van Dyke Parunak et al. 1998). Especially for modelling complex adaptive systems, the bottom-up approach has been developed successfully (Miller and Page 2007). ABM enables the implementation of heterogeneous agents, geographical space and discrete time steps (Wilensky and Rand 2015) and allows the simulation of endogenous dynamics based on bounded rationality and satisficing (Simon 1987) decision heuristics instead of individual optimisation. Moreover, within- and between-group level learning leads to endogenous transformation as processes can be modelled in a generative way (Epstein 2006). The agent-based methodology is not yet another tool to deliver predictive analysis, but a complement to theoretical and qualitative analysis capable of enriching theory and policy advice with path-dependent scenario analysis. The approach aims for uncertainty analysis, as highlighted by Edmonds and ní Aodha (2019) and exemplified (among others) by Rengs and Scholz-Wäckerle (2019), Rengs et al. (2020) and Gerdes et al. (2022).<sup>1</sup> Altogether, this makes ABM a perfect candidate for simulating, testing and experimenting with utopias and alternative imaginaries in computational laboratories, as it enforces utopian thinkers to sharpen and refine arguments and narratives. The agent-based approach allows to enrich a model's environment, the conditions and structures of production and coordination via detailed and concrete implementation, as we aim to demonstrate in the following sections.

Section 2 discusses the theoretical foundations of commonism. Section 3 introduces COMMONSIM, the agent-based model of commonism. Section 4 discusses a series of simulation experiments on the aforementioned research questions. The baseline model is tested on behalf of exclusive compared to inclusive allocation, as well as a culture-dependent allocation mechanism. As exclusive allocation cannot provide stability for groups with certain cultural traits, two different institutional mechanisms are tested, in order to demonstrate the robustness of the communist utopia even in hostile situations, i.e. (1) a common inventory as an additional buffer across cultures and (2) indirect reciprocity. The results indicate the success of both

<sup>1</sup> Compare Dosi and Roventini (2019) and Cincotti et al. (2022) for an overview of agent-based macro-economics.

mechanisms in stabilising cooperation on a large scale, albeit with different dynamics as we indicate with a meso-level analysis of the networks' complexity.

## 2 Theoretical foundations of the commons-based utopia

Utopianism has always been a controversial topic in critical social research as well as in social movements. Starting with Marx's critique of so-called utopian socialism, which is more differentiated than often suggested (Leopold 2020), the most influential Marxian orthodoxies took a harshly negative stance towards utopias to underline their own (sometimes questionable) scientific character. The legitimacy of utopian thought was further marginalised by the dogmas of value neutrality and positivism in early sociology, which—in the case of Max Weber—functioned as a legitimisation for the passive revolution (Rehmann 2015). Alternative visions of sociology, which were quite widespread in the early days of the emerging discipline as well, never gained the same long-term influence. For instance, H.G. Wells, today best-known as a science fiction writer, tried in vain to get a chair in sociology. For Wells (1906), the creation of utopias was “the proper and distinctive method of sociology”. Similarly, Otto Neurath suggested in the 1920s that social scientists should formulate ideals of social arrangements in a utopian style, thus adopting a creative stance aiming at discussing scientific proposals with a community (Neurath 2004; Da Cunha 2016).

Similarly, the recent decades have seen a revival of scientific utopianism, ranging from treating it as a distinct and powerful methodological strategy (Levitas 2013; Wright 2010) to envisioning of real utopias (Devine 2002; Albert 2003; Laibman 2012; Saros 2014; Sutterlütti and Meretz 2018; 2023; von Redecker 2020; Apolito 2020; Dapprich 2020). These writings outline possible societies and develop theory-based utopias in difference to simple wishful thinking. They focus on social potentials, viability and tendencies to realise a society given the current state of knowledge and discuss general societal characteristics, how utopian societies organise reproduction, coordinate themselves, make decisions, distribute unpopular tasks etc.

### 2.1 Beyond market economies and state-socialist utopias

In the nineteenth and twentieth centuries, many debates on social alternatives have alternated between capitalism and state-socialism. Depending on the specific design, they rely on mixed forms of market and state institutions to coordinate social provisioning<sup>2</sup> based on exchange or redistribution (Polanyi 1944; Wright 2010; Saros 2014). In market and state-planned economies, exchange is the dominant form for the allocation of goods and services. Extorted contribution of wage labour is constitutive for this dominance, and money is the most common unit of account to facilitate the exchange. Mediation via money enables a coherent societal coordination (Marx 1887) by coupling “giving” and “taking” on the individual level (Bockelmann 2020).

<sup>2</sup> From a heterodox perspective, provisioning must be the key subject of inquiry in economic research; see e.g. Ferber and Nelson (1993).

Both capitalism and state-socialism rely on exchange values and originate in wage labour relations to match individual needs and contributions, societal necessities and real constraints, with provisioning systems (Kurz 1991). The main difference between market and state-planned coordination is about who sets the price, leading to a decentral competition-driven or a centralised command economy. In market economies, profit-seeking is not an individual trait but a societal condition necessary to survive in competitive markets (Marx 1887). To survive, businesses focus on exchange value rather than use value, threatening social and ecological needs and leading to a capitalist domination of all aspects of society and life (Ferber and Nelson 1993; Jo 2011). Critical environmentalists, for instance, argue that consumption-orientation as a compensation for everyday self-suppression leads to employment as a mechanism of societal integration (Schor 1991) fostering economic growth at odds with ecological concerns (Georgescu-Roegen 1971). Feminist theories link capitalist and state-socialist patriarchy to the division between a paid public sphere of “male” production and an unpaid private sphere of “female” reproduction and care, undermining the latter (Biesecker and Hofmeister 2010; Ferber and Nelson 1993; Scholz 2000; Winker 2021). Moreover, the state is also dependent on the functioning of accumulation; thus, it has only relative autonomy vis-à-vis the market and must ultimately guarantee profit accumulation and growth (Hilferding 1910, Baran and Sweezy 1966).

In contrast, many utopias organise society on the basis of generalised reciprocity rather than exchange relations and motivations rather than the extorted contribution of wage labour. These utopias are at the core of critical theories (Schlemm 2019), and commonism is one of them.

## 2.2 Commonism

The utopia of commonism has been developed by Sutterlütти and Meretz (2018; 2023) and is based on three levels: the individual, the commons and the society.

### 2.2.1 Micro level: the individual

Humans are, according to critical psychology, societal beings that are neither egoists nor altruistic do-gooders, but act according to needs given in certain social structures that they themselves build and reproduce every day (Holzkamp 1983; 2024; Tolman 1994). Traditional psychological theories tend to treat societal conditions only as variables determining people’s actions. This underestimates or neglects the fact that people are not passive automatons who algorithmically react to inputs, but that they create and modify the conditions they face. They interpret life aspects according to their needs, emotions, motivations and perceptions; they decide how they want to deal with conditions, whether to ignore them, accept them or change them according to their reasoning (Graeber and Wengrow 2021).

Critical psychology reflects societal conditions and distinguishes between sensual-vital and productive needs.<sup>3</sup> In difference to preferences and wants, these needs are universal and not substitutable (Gough 2015), although they always take specific historical forms. While sensual-vital needs are oriented towards food, shelter, sex etc., productive needs result from human aspirations to gain agency for the societal provision of living conditions. Human sources of need satisfaction are societal, and as a result, humans strive for agency to “have the sources of satisfaction at their disposal” (Holzkamp 1983, p. 246; 2024). Humans who cannot make provisions because they cannot create and control their living conditions are not agents of their own lives. Agency thus depends on others and on society as a whole; it is the “individuals’ availability of their own living conditions while participating in the availability of the societal process” (ibid., p. 241). Human beings strive for the agency to satisfy their sensual-vital needs, and the driving force behind this striving for agency are the productive needs. They are the “need basis for individual participation in the availability of the total societal production/reproduction process” (ibid., p. 242). Thus, humans are motivated to participate in societal reproduction to gain agency, which can proactively ensure the satisfaction of sensual-vital needs. Motivation is the individual’s emotional evaluation of future gains counter-weighted with risk and effort. Within voluntary and caring contributions, motivation moves between lust and necessity (Kratzwald 2014). People are motivated to do things that are exhausting, tiresome and even dangerous if the outcome outweighs the risk and effort. Emotions evaluate a situation based on individual needs; hence, all decision-making processes are rational and emotional at the same time. The capitalist and patriarchal critique of most emotions and their alleged irrationality stems from the fact that many emotions reveal individual suffering and foster resistance (Pohl 2004). Wage labour societies impede motivation and satisfaction of productive needs because their production is oriented towards exchange value rather than use value. Capitalism binds need satisfaction largely to the exclusion of others, thus promoting selfishness, segregation and competition. A utopia in which one’s needs can be better satisfied by including others will produce very different social relations and individual attitudes.

### 2.2.2 Meso level: the commons

According to Elinor Ostrom, commons are common-pool resources that are collectively used and governed (Ostrom 1990). Social commons theory broadened the research focus, examining the collective governance of means of production and consumption (Bollier and Helfrich 2012) and the associated need-oriented production of goods as commons rather than commodities. Thus, commons are resources or products, which emerge from commoning, i.e. the self-organised process of shared need-oriented production, management, care or use of these means (de Angelis 2017).<sup>4</sup> A commons project can be compared to a firm in a capitalist provisioning

<sup>3</sup> A further classification and hierarchical ordering of needs (Maslow 1943) is rejected, since “higher” needs are as important for human-societal beings as “lower” ones.

<sup>4</sup> For example, the atmosphere is thus not a commons, since there is no commoning: no process of shared need-oriented producing, managing and caring—only a process of disorganised over-use. But it could be, as everything could be a commons, if there is commoning involved.



system. However, purpose, organisation and resource access are very different. In commons, people care and produce not because they are forced to do so by wage labour or market pressure, but out of their productive needs. Their goal is to produce use values to directly satisfy sensual-vital needs, not exchange values to obtain money to indirectly satisfy sensual-vital needs. Cutting off moneyless people from satisfying their needs although means to do so, for example. Many contemporary existing commons still produce for and/or depend on the market and thus its logic of exclusion contrasts with the need orientation of self-organisation. Moreover, interpersonal direct cooperation is dominant—compared to a possible transpersonal society-wide cooperation in commonism—which is due to the niche character of commons projects under capitalist conditions (Bollier and Helfrich 2012).

Activities are organised by the participants themselves, i.e. self-organisation in the comprehensive sense. They set the rules of cooperation, determine their decision-making procedures and regulate conflicts (Ostrom 1990). An important prerequisite for self-organisation is the availability of conditions that correspond to the interests of the commons' members, including the resources and means needed to realise the purpose. Since there is no way to force people to contribute or collaborate, the conditions for participation are usually designed to be inviting. This makes it easier for people to have good reasons to participate in the commoning process and to voluntarily contribute to the commons. Since participation is essential to achieve the goals of the commons, a tendency towards inclusion of contributors evolves. In the commons, therefore, it is functional to make the needs of others the premise of one's own actions and to resolve conflicts through communication (Habermann 2016). This logic of inclusion is not only established within the commons projects, but between them. Commons are interdependent and therefore have to take into account the needs of other re/producers in order to obtain resources, time and preliminary products, which leads to a society-wide incentive to include the needs of others. The logic of inclusion is at the core of the commons, but it can only unfold, if the surrounding social environment operates with the same logic, which is the case for commonism (Sutterlütti and Meretz 2018, p. 160; 2023).<sup>5</sup>

### 2.2.3 Macro level: the society

In commonism, social structures produce, demand and facilitate inclusion and solidarity, rather than relying on individual altruism. Moreover, inclusion is not only partial and an instrument within social conditions of exclusion, but also tends to generalise. People gain agency by including others, who in turn include others,

<sup>5</sup> The emphasis of this article is on commoning in the social formation of a utopian society, so we abstract from transformative approaches such as those found in Buen Vivir, Ecological Swaraj, Cecosesola or the just-ecological approach by Obeng-Odoom (2020). However, we see the grand potential of these approaches and share the critical stance contra the neo-institutionalist use of the commons (e.g. Ostrom's work on common-pool resources) with them and emphasise in a similar way the process of commoning, as highlighted above. Transformative approaches are obviously forced to consider concrete local and/or historically specific conditions. Therefore, a synthesis between the aforementioned transformative approaches and our theoretical conceptualisation of the utopian structures of commonism would fill a substantial research gap, but goes beyond the scope of this paper.



that the development of one's own agency is generalised, that is “an association, in which the free development of each is the condition for the free development of all”, as Marx and Engels put it (1848). Such a utopia creates conditions that encourage people to cooperate therefore. Thus, people build workspaces according to their productive needs and find satisfying solutions to conflicts in agreement with their partners. Commons that perform better in these tasks will experience support and contribution, become best practices of cooperation and create templates for others (Bollier and Helfrich 2019).

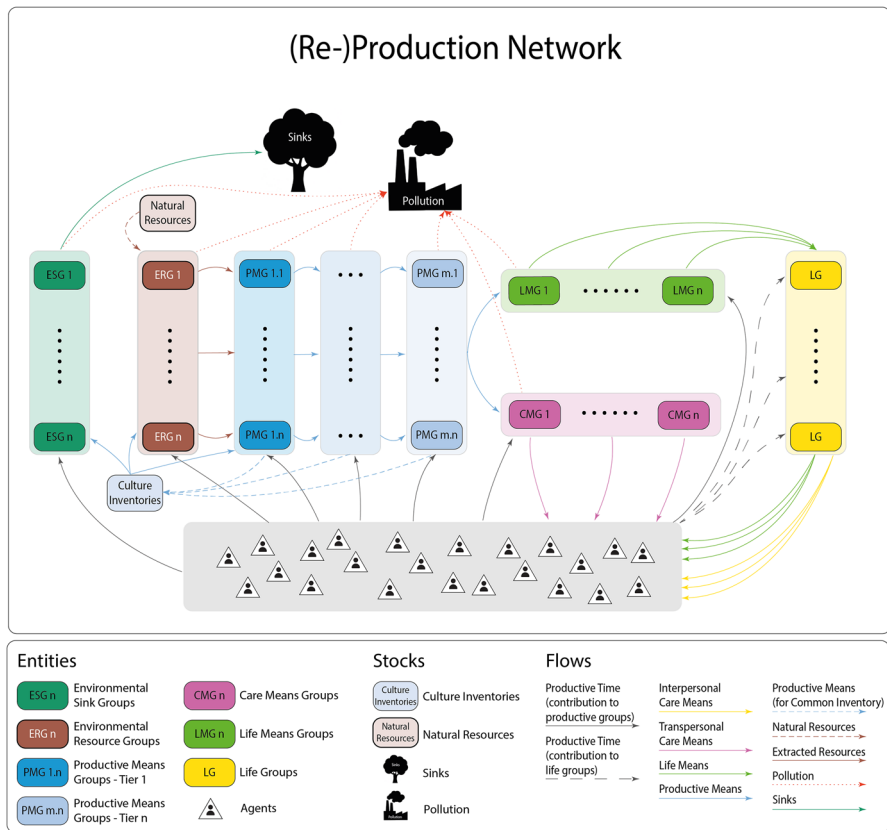
To ensure a dynamic of inclusion, commonism relies on semi-autonomous inclusive decision-making (Carlisle and Gruby 2019). This means that the agency of collectives and individuals to decide upon their goals and tasks is guided by their dependency on others as part of complex adaptive production networks. Agents act inclusively because cooperation cannot be enforced. In a commons, workers use means of production and decide how to distribute goods and services. In order to receive the respective goods and services of others, workers must take into account the needs of others. Semi-autonomous collective availability in free cooperation is one way of organising the real socialisation of means and products of production. Immaterial means such as blueprints, information, videos or organisational patterns are shared and freely available. Material means are at the semi-autonomous disposal of collectives.

Capitalism has developed highly complex production chains of a huge variety of products driven by profit-seeking. It is likely that in a need-driven society, the bandwidth of products (at least equal competing ones) as well as the depth of the division of labour will be reduced—simply for ecological reasons. However, commonism will not revert to local interpersonal production which would lose the power and efficiency of transpersonal cooperation (Marx 1887, p. 230). We address the basic complexity of a global modern economy in a nutshell, using a multi-tier and multi-sectoral approach in our model (see Fig. 1).

While in capitalism markets act as information processors, how will mediation be realised in commonism, where a central information processing unit (e.g. a planning bureau) is not assumed? First of all, even capitalist firms depend on internal planning, and some of them reach the size of a medium national economy, e.g. Walmart, Amazon etc.<sup>6</sup> Although they coordinate the physical flow of goods, price signals remain the key information. Thus, all known negative effects such as externalisation, exploitation and endless growth are still present even in the case of internal ex ante central planning. In commonism, these effects are avoided because the motives and criteria for decisions are need-based and distributed within the production network.<sup>7</sup>

<sup>6</sup> Walmart uses internally algorithms for ex ante planning and coordination of their entire production and supply chains, in order to minimise the frictions that occur when market signals are used for ex post coordination of the production network. On the other hand, this is what happened in the case of SEARS, where the artificial implementation of market mechanisms—by splitting the company into numerous fractions of smaller firms—led to a complete bankruptcy due to increased inefficiency, higher transaction costs and bullwhip effects. Compare Phillips and Rozworski (2019) as well as Morozov (2019) among others for those cases.

<sup>7</sup> In a recent publication, the aspects of local information, distributed planning and coordination along production chains are discussed; we argue that based on uniform protocols, ex ante coordination can generally be effectuated in time (see Meretz and Sutterlütti 2024, forthcoming).



**Fig. 1** Basic structure and flow-chart of the model

In our model, we implement three intermediary levels (plus the supply of resources and final livelihood means production) with a simple coordination mechanism, which takes place by requesting products from upstream producers. The delivery of these intermediary and final means ensures economic reproduction for all production tiers. This is ultimately driven by mutual cooperation, since everyone's satisfaction of productive needs depends on it. If there is a shortage, then other intermediary producers are requested.

### 3 Modelling the commons-based utopia

The agent-based model COMMONSIM presented in this part of the article is based on the above-described utopia of commonism. We start with a description of the social structure represented in the model; then, agent characteristics are introduced, followed by the production, coordination and social-ecological provisioning mechanisms.

### 3.1 Social structure: life and production groups

COMMONSIM represents an artificial society with individual heterogeneous agents interacting in social networks for social-ecological provisioning (see Fig. 1).<sup>8</sup>

The networks represent the private and public spheres; they organise social life, structure social and economic dynamics; form the basis for all reproduction and satisfaction processes; and adapt to their members in reflexive terms. Each agent is part of at least one, at maximum two different immediate social networks, called groups. There are two types of groups: life groups and production groups. With one to ten members, life groups are the smallest and most intimate networks agents are part of; they represent family-like structures plus extended circles of close persistent relations. Furthermore, agents are also part of production groups producing either intermediate or final means (e.g. machines, wood, food or music), resources, sinks or care means (see next section). These groups have one to about 300 members at initialisation, depending on the sector. By initialisation and through the course of the simulation, the care means groups are generally the largest ones in terms of members. Hospitals and care infrastructure need a lot of agents in order to treat patients directly as well as to use and operate its comparably high developed machinery and equipment. In terms of sector and group size, the life means sector and the highest productive means sector follow, as there are comparably more people needed for final distribution and delivery as well as for fine-tuning of last stage intermediary input than in lower productive means sectors. Where we assume the highest agent productivity in final life means production, this sector is otherwise structured through the highest productive means intensity (same for care means), therefore resulting in a similar sector size as the final productive means sector (although the latter with far lower agent productivity). Furthermore, agent productivity increases upstream through the productive means sectors and sector size decreases, as we assume that machines work more efficiently per output the more upstream the sector, therefore demanding less agent input. Otherwise, the intensity of productive means in those sectors is assumed to be the same, lower than in life and care means and higher than in the resource sector. The latter has the lowest productive means intensity, but a slightly higher agent productivity than in productive means sector, as mining machinery may achieve more output per worker.<sup>9</sup> Sector and production group sizes change endogenously throughout the simulation, but the relative size stays the same in general. Agents are connected via links with the production groups, and thereby with other group members.

<sup>8</sup> COMMONSIM is more complex than most of current agent-based macroeconomic models in terms of sectoral complexity, but very similar to those in terms of size, scale and spirit; see e.g. Caiani et al. (2016), Rengs and Scholz-Wäckerle (2019) or Gerdes et al. (2022).

<sup>9</sup> Compare Table 5 for a complete overview of used parameter settings for agent productivities and intensities of productive means for all sectors.

**Table 1** Configuration of cultural traits

Ecologist Culture	ego-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	leisure-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	eco-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	prod-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Traditionalist Culture	ego-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	leisure-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	eco-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	prod-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Modernist Culture	ego-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	leisure-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	eco-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	prod-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Random Culture	ego-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	leisure-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	eco-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	prod-level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

### 3.2 Agents

The population consists of a heterogeneous set of agents. All agents are part of groups and differ along four personal characteristics, which are a fundamental set of parameters influencing the behaviour and decisions of agents ( $c_{i,t}^k \in [0, 1]$ ), where  $i$  denotes the agent,  $t$  the time-step and  $k$  the specific characteristic. If average characteristics are initialised with or develop into extreme values, the system becomes instable. Therefore, agents' characteristics are distributed around some tested values (see Table 1).

The four personal characteristics are as follows:

- (1) Ego, a spectrum between egoistic and altruistic behaviour, which influences how affected the agents are by their social networks ( $c_{i,t}^{\text{ego}}$ )
- (2) Leisure, a spectrum between leisure and activity focus, which guides the decision on how much time an agent wants to be active in production and life groups ( $c_{i,t}^{\text{leisure}}$ )
- (3) Eco, a spectrum between being indifferent and very concerned about the environment, which affects an agent's evaluation of the environment and consumption decisions ( $c_{i,t}^{\text{eco}}$ )
- (4) Prod(uctivity), a spectrum between being indifferent and very concerned about output, which influences how much an agent values being productive ( $c_{i,t}^{\text{prod}}$ )

#### 3.2.1 Group culture

All agents are part of a group culture, depending on the configuration of their personal characteristics. From a methodological point of view, the different group cultures implemented might also be understood as relational positions in the social space, reflected by habitus, in terms of Bourdieu (1984). The cultures refer—as

shown below—quite well to empirically identifiable strata to be found in contemporary Germany; our usage is not only motivated by a reference to empirical reality but to explore and explain (namely experiment with) various causalities in the simulation. We may link those relational positions in the social space as mental images of group cultures to a recent study on “socio-ecological mentalities” (Eversberg and Fritz 2022, p. 975): “From the perspective proposed here, the opinions voiced and the actions taken in relation to these issues are expressions of incorporated dispositions, or schemes of perception, evaluation and action acquired in the course of socially specific biographical experience. In their totality as a ‘syndrome’, these dispositions make up what we call mentalities”. The research group classified the mentalities according to three major “camps” (ibid., p. 978): (1) eco-social camp (~35%), (2) liberal-escalatory camp (~40%) and (3) authoritarian-fossilist camp (~25%). We generate such differentiation on the basis of the aforementioned main behavioural agent parameters. The different group cultures calibrated for the simulation serve as such mental images and limiting concepts for a diversity and heterogeneity of agents. With the initialisation of the simulation, each agent is part of a specific cultural group that shares some characteristic tendencies. Depending on this cultural group, the personal characteristics are initiated for each agent based on the distribution shown in Table 1, where each characteristic falls into the spectrum indicated for the specific culture.

Agents may adapt their characteristics to the aggregate behaviour (trends) of their social networks,  $(c_{pgc,trend}^k, c_{lgc,trend}^k)$ , where *pgc* refers to the productive group and *lgc* to the life group. Cultural groups develop characteristic and distinctive parameter combinations thereby and adapt with agents entering/exiting the group. Asynchronously, agents adapt the characteristics  $(c_{i,t}^k)$  every half year with a 25% chance towards the trend of their groups. The adaptation is weighted by the ego level: agents with a high ego level are less influenced by their social networks.

$$c_{i,t}^k = c_{i,t-1}^k + \left( \left( 0.5 \times c_{pgc,trend}^k + 0.5 \times c_{lgc,trend}^k \right) - c_{i,t-1}^k \right) \times 0.05 \times \left( 1 - c_{i,t-1}^{ego} \right). \quad (1)$$

The adaptation may push the agent into a new culture if characteristics meet the latter’s parameterisation. Next to cultural characteristics, agents have a set of  $icm_{i,t}^{target}$  need for interpersonal care means,  $tcm_{i,t}^{target}$  need for transpersonal care means,  $lm_{i,t}^{target}$  need for life means and  $pt_{i,t}^{target}$  the total hours an agent wants to be active; conditions  $(cond_{i,t}^{need})$ ; priorities  $(prio_{i,t}^{pgs})$ ; and emotions  $(emo_{i,t}^k)$ .<sup>10</sup>

### 3.2.2 Sensual-vital needs

Satisfying sensual-vital needs is provided by (1) interpersonal care means  $(icm_{i,t}^{target})$ , e.g. cleaning, cooking and taking care of children and elders; (2)

<sup>10</sup> A list of all conditions, emotions, priorities and all other variables and parameters can be found in the ODD protocol, part of the supplementary material. All variables and parameters used in the following equations are included in the [Appendix](#).

transpersonal care means ( $tcm_{i,t}^{target}$ ), e.g. hospitals, schools and nursing homes; and (3) life means ( $lm_{i,t}^{target}$ ), e.g. food, music and housing. Sensual-vital needs are satisfied if agents receive the required means, either directly from the respective production group (as in the case of transpersonal care means) or via its life group distributing interpersonal care means and life means. Needs are updated every round (see Eqs. 2 and 3). Agents request a minimum amount of both types of care means ( $icm_{min}$ ,  $tcm_{min}$ ) each round. Given a probability for care needs ( $prob1$ ), agents increase this minimum amount. The increase is different for each agent, depending on the individual severity of extra care demand ( $w_{i,t}$ ), which is an individual level of need for care, such as sickness, weighted with parameter ( $a_1$ ) and the ego level (agents with a high ego level have a higher need for interpersonal care means). The target value ( $icm_{i,t}^{target}$ ,  $tcm_{i,t}^{target}$ ) is then used to signal and request those means.

$$icm_{i,t}^{target} = icm_{min} + w_{i,t} \times icm_{min} \times a_1 \times \left(0.5 + \left(N\left(c_{i,t}^{ego}; 0.1\right)\right)\right). \quad (2)$$

$$tcm_{i,t}^{target} = tcm_{min} + w_{i,t} \times tcm_{min} \times a_1. \quad (3)$$

Interpersonal care means are requested from and provided (“produced”) by the agent’s own life group, while  $tcm$  stems from a care means group. All groups distribute the means after the production process, the life groups among their members and the production groups among the requesting groups.

The need for life means ( $lm_{i,t}^{target}$ ; see Eq. 5) is influenced by the groups they are in, i.e. the group-impact  $gi_{i,t}$  (Eq. 4), consisting of agents’ past experiences and past consumption, as well as the average consumption from the groups they are part of:  $mean(lm_{pgm,j,t-1}^{current}; lm_{lgm,j,t-1}^{current})$ , where  $pgm$  represents the average of the production group and  $lgm$  of the life group, weighted with the ego level (strength of influence of the social networks). Agents adapt their needs dependent on other group members; however, agents with a high ego are influenced less by them. Moreover, the ego level also impacts the network effect, assuming that agents with a high ecological concern are more inclined to decrease consumption and agents with a low ecological concern are more inclined to increase consumption. Depending on the wellbeing of the agents, the strength of the effects changes (based on  $wi_{i,t}$  the wellbeing impact and  $ei_{i,t}$  the ego impact). If agents’ wellbeing is low, they more strongly increase consumption and less strongly decrease consumption (depending on the direction of the adaptation). If agents’ wellbeing is high, they less strongly increase consumption and more strongly decrease consumption. Parameter values are included in the Appendix (Tables 3, 4, 5, and 6).

$$gi_{i,t} = \left(mean(lm_{pgm,j,t-1}^{current}; lm_{lgm,j,t-1}^{current}) - lm_{i,t-1}^{current}\right) \times c_{i,t}^{ego} \times ei_{i,t} \times \left(randomfloat\left(1 - c_{i,t}^{eco}\right)\right). \quad (4)$$

$$lm_{i,t}^{target} = lm_{i,t-1}^{current} \times \left(1 + randomfloat\left(c_{i,t}^{ego} \times wi_{i,t}\right) + gi_{i,t}\right). \quad (5)$$

The need for life means is collected by life groups from all its members and then requested from the life means groups as a bundle. If life groups receive sufficient means to satisfy all needs of their members, every agent receives as much as requested. However, in the case of shortages, life groups distribute based on the amount *required* ( $lm_{i,t}^{\text{target}}$ ) as well as on the *priority* ( $prio_{i,t}^{\text{lm}}$ ) each agent assigns to this specific need.

### 3.2.3 Productive needs

Productive needs describe the wish of agents to actively participate in society. They are satisfied by contributing to reproduction processes in life and production groups. The agents like to be active for an exact number of hours they designated to each group. The time budget, however, is dependent on the reproduction plan of the groups. If the plan requires fewer hours input than offered by all its members, each agent has to be less active. The available hours in this case are distributed based on the required hours as well as the priorities of each agent concerning the specific need.

The level of *productive needs* (the total hours an agent wants to be active,  $pt_{i,t}^{\text{target}}$ , see Eqs. 6 and 7) is a maximum of 112 h per week (16 h a day). The level depends on the personal characteristic *leisure* ( $c_{i,t}^{\text{leisure}}$ ); agents with a high leisure level have a lower level of productive needs. The overall productive needs are also influenced by an emotional impact, which is the emotional evaluation of the satisfaction of sensitive-vital needs, the environmental and the societal condition ( $emo_{i,t}^{\text{mean}}$ ). Moreover, this level is reduced if the agent has an extra demand for care ( $w_{i,t}$ , limited by the link between care demand and time spent by agents ( $ct_i$ )), addressing that if agents need specific care, they are less able to work. The total amount of hours is distributed between the life and production group the agent is a member of. The share of each group depends on the emotions of an agent, its priorities and the situation in the groups (if contributing people are needed or not).

$$pt_{i,t}^{\text{total}} = 112 \times \left(1 - c_{i,t}^{\text{leisure}}\right) \times \left(1 + \frac{\left(1 - emo_{i,t}^{\text{mean}}\right)}{2}\right). \quad (6)$$

$$pt_{i,t}^{\text{target}} = pt_{i,t}^{\text{total}} \times \left(1 - \left((1 - w_{i,t}) \times ct_i\right)\right). \quad (7)$$

### 3.2.4 Conditions

Conditions describe the extent to which the needs are satisfied. Each agent's need has a corresponding condition, defined as:

$$cond_{i,t}^{\text{need}} = \frac{need_{i,t}^{\text{current}}}{need_{i,t}^{\text{target}}}. \quad (8)$$



The target is the value an agent aspires and the current what it received, or actualised in case of productive needs. Conditions have a value range of [0,1]. Next to agents, groups are also evaluating their conditions regarding the planning, production and delivery process in similar terms. These conditions can be observed by the agents.

### 3.2.5 Emotions

Agents have emotions about the personal, group, societal and environmental conditions which they value with respect to their sensual-vital and productive needs. Emotions influence the priorities of the agents (next section) and thereby influence the decision-making processes. Emotions are updated once agents have assessed the condition of the given need. If the current condition is higher than the emotion, the emotion is increased, and vice versa. In a second step, agents adapt their emotions to the emotions of their groups, relative to their ego level, weighted with the adoption parameter  $a_2$  (Eq. 9; for parameter values, see Appendix). If the average emotion of a group is worse than that of the agent, the agent reduces its individual emotion, and vice versa. In Eq. (9),  $k$  denotes the type of emotion.

$$emo_{i,t}^k = emo_{i,t-1}^k + \left( emo_{group,j,t-1}^k - emo_{i,t-1}^k \right) \times a_2 \times \left( 1 - c_{i,t}^{ego} \right). \quad (9)$$

All emotions combined create the emotional wellbeing variable, which indicates how well an agent is doing emotionally.

### 3.2.6 Priorities

Agents prioritise between different aspects of their lives. These priorities reflect the experiences from the past. There are two categories of priorities, those related to sensual-vital needs (obtaining means) and those regarding productive needs (contributing hours). Each category prioritises only its components; components of different categories cannot be compared. The sum of all priorities within one category always adds up to 1; hence, the priority of each component is a fraction of 1.

### 3.2.7 Priorities of sensual-vital needs

These are priorities to obtain means to satisfy sensual-vital needs related to icm, tcm and lm. Agents update their sensual-vital needs priorities ( $prio_{i,t}^{svn-k}$ , where svn-k denotes the sensual-vital need) based on their emotions and motivations. If the emotional rating is high, the respective priority is decreased, and vice versa, which results in high priorities if an agent is not doing so well in a respective area (low condition  $\rightarrow$  high priority) and low priorities if the agent is doing well (high condition  $\rightarrow$  low priority). In case of shortages, the priorities influence how the means are distributed to agents.

$$prio_{i,t}^{svn-k} = prio_{i,t-1}^{svn-k} + \left( randomfloat(((1 - emo_{j,t}^{svn-k}) + moti_{j,t}^{svn-k})/2)) + 0.5. \quad (10)$$

### 3.2.8 Priorities of productive needs

Priorities of productive needs indicate the importance of the different sectors and the life group for each agent. Agents may increase the priority for a sector or group ( $prio_{i,t}^{pgs}$ , where pgs denotes the sector of the production group, and  $prio_{i,t}^{lg}$  the life group priority) if there is a lack of time in the sector or if the agent noticed a lack of specific lm or tcm needs in its own groups. Agents increase a priority based on the emotions within their groups regarding the sensual-vital needs satisfied by that sector ( $emo_{group,j,t}^k$ ), limited by the ego level:

$$prio_{i,t}^{lg} = prio_{i,t-1}^{lg} + \left(1 - emo_{group,j,t}^k\right) \times a_3 \times c_{i,t}^{ego}. \quad (11)$$

$$prio_{i,t}^{pgs} = prio_{i,t-1}^{pgs} + \left(1 - emo_{group,j,t}^k\right) \times a_3 \times \left(1 - c_{i,t}^{ego}\right). \quad (12)$$

### 3.2.9 Entry and exit in production groups

Agents are willing to change the production group if they are currently not active in the sector with their highest priority. If so, they communicate a list of their four highest prioritised sectors, to enhance the coordination between agents and groups, especially when the latter look for new members. Moreover, agents may decide to exit a production group if this group could not satisfy their productive needs over the past 4 weeks (i.e. offered work hours are not accepted).

## 3.3 Production, coordination and social-ecological provisioning

The simulated provisioning process reflects processes envisioned by commons theory, based on an ex ante coordination process guiding the production and delivery of means. The utopian economy rests on a relatively complex production network, involving six different sectors (see Fig. 1). Each *means* to be produced requires two or three complementary inputs. All means are produced by production groups, except interpersonal care means provided by life groups. Group culture shapes the organisation of the production process and the coordination between groups.

### 3.3.1 Groups

*Environmental resource groups* (ERGs) extract natural resources and prepare them for further use. Apart from the resource stock, they need machinery ( $x_{j,t}^{pm}$ ) and person-hours ( $x_{j,t}^{ph}$ ). ERGs receive the needed machinery from a cultural specific inventory, which is a storage for machinery that all productive means groups

of the same culture (see below) fill during the production process. If the cultural specific inventory is empty, they can receive machinery from the productive means groups. Apart from producing resources, ERGs create pollution and destroy sinks during the production process.

*Environmental sink groups* (ESGs) reproduce the sinks that sequesterate pollution from the biosphere, for example by cultivating ecosystems. As an input, they need machinery and person-hours. Like ERGs, ESGs receive machinery from the cultural specific inventory, or if needed, from the productive means groups. ESGs observe the level of accumulated and planned pollution for production.

*Productive means groups* (PMGs) produce means of production, which can be understood as machinery or intermediary means needed by all other production groups as an input. PMGs are located on different tiers. In the presented simulation, three tiers are implemented; however, the number is scalable. Generally, each sector needs person-hours and means of production produced by the previous tier; only the first tier in the matrix additionally needs resources  $(x_{j,t}^r)$  from the ERGs. First-tier PMGs may draw machinery from the inventory, same as ERGs. PMGs create pollution during the production process.

*Life means groups* (LMGs) produce the final life means (lm) agents consume. The means are produced with person-hours and machinery (from the final PMG tier). The final output is provided to life groups, which are distributing it to their members. LMGs also create pollution.

*Care means groups* (CMGs) produce transpersonal care means (tcm), e.g. schools and hospitals. As an input, person-hours as well as machinery produced by the lowest PMG tier is necessary. The output is directly provided to the agents. Contrary to life means, care means cannot be kept in inventories.

*Life groups* produce interpersonal care means (icm), e.g. caring, cleaning and cooking. As an input, they only require person-hours. The output is directly redistributed to the members of the group.

### 3.3.2 Coordination mechanisms

The provisioning process is based on ex ante coordination; only care groups operate on ex post coordination basis. Ex ante coordination implies that all groups plan their production based on the plans of the groups they want to deliver to (see Fig. 1). Those plans depend on the sensual-vital and productive needs of agents in the network. Production groups estimate the number of agents needed for production and the amount of input they require from the previous tier. If a group does not have sufficient people, it tries to find new members by contacting agents that are not in production groups or that announced to change to a group of another sector. If agents are found, they are admitted to the group.

The starting point of the planning process is the needs of the agents communicated to the LMGs. After LMGs planned the production, the information of needed inputs is communicated to the PMGs on the lowest tier. Afterwards, PMGs plan production in the sequence of tiers, based on the previously signalled demand. They include a reserve buffer in order to prepare for unexpected shocks. Eventually, environmental resource groups (ERGs) make their plans as well as environmental sink groups (ESGs).

Overall, agents coordinate in stigmergic terms, i.e. agents and groups communicate in their respective groups and between those via signs. After groups have signalled their demand, ERGs receive the needed machines from the cultural specific inventory (or from PMGs, if the common inventory is empty) and start to mine. After production, they deliver the resources immediately to first-tier PMGs, which also draw machinery from the common inventory. Then, production means are produced and delivered downstream sequentially. The process repeats until life means groups are reached, which produce and deliver the final means to the life groups of agents. At last, ESGs produce the sinks. The limiting (complementary) production function ( $q_{j,t}$ ) is given below; parametrisation depends on sector.  $a_4^{\text{sector}}$  represents agent productivity,<sup>11</sup>  $a_5^{\text{sector}}$  production mean intensity,  $a_6^{\text{sector}}$  resource intensity,  $x_{j,t}^{\text{pm}}$  production means currently available,  $x_{j,t}^{\text{ph}}$  person-hours currently available and  $x_{j,t}^{\text{r}}$  resources currently available.

$$q_{j,t} = a_4^{\text{sector}} \times \min \left( \left( \frac{1}{a_5^{\text{sector}}} \times x_{j,t}^{\text{pm}} \right), \left( x_{j,t}^{\text{ph}} \right), \left( \frac{1}{a_6^{\text{sector}}} \times x_{j,t}^{\text{r}} \right) \right). \quad (13)$$

After provision of means, PMGs move half of the undistributed means they have left in stock to their culture-specific inventory, subject to a waste rate ( $a_7^{\text{sector}}$ ). Moreover, the intermediary inputs of production groups are not depleted in the production process, but are subject to a sector-specific depreciation rate ( $a_8^{\text{sector}}$ ), while resources, life means, transpersonal care means and interpersonal care means are fully depleted by consumption. Transpersonal care means are produced based on past demands. Contrary to life means, the *tcm* are delivered on demand directly to the agents without involvement of the life groups.

### 3.3.3 Production network updating—allocation mechanisms

Every 12 ticks, all groups update their networks, by either cancelling links to groups they deliver means to, cancelling links from groups they are receiving means from or creating new links. Links are cancelled if a group does not want to cooperate with the connected group anymore, based on cultural disparities and/or unmet cooperative requirements. New links are created if the groups did not receive enough means in the past round or if they have fewer links than the minimum number of links. Groups have a preference list of cultures they are willing to cooperate with. This list can be updated, depending on the setting. The model allows for three different allocation mechanisms: exclusive-, inclusive- and culture-dependent allocation.

**Inclusive allocation** Groups are agnostic about the culture of the other groups. They don't distinguish between the groups, regardless of their culture, and potentially receive from and send to all other groups.

<sup>11</sup> Usually indicated as “labour productivity” in economic production functions.

**Culture-dependent allocation** Groups behave differently, depending on their culture. The default is the inclusive allocation mechanism. However, based on the exclusion parameter ( $ex_{i,t}$ ), a group may be more exclusive than others in terms of culture. The parameter's value is given by the average of ego- and productivity level of each culture. Given a probability for  $ex_{i,t}$ , a group updating the network may replace the inclusive mechanism with the exclusive. As a result, it may cancel links to groups of other cultures or prohibit the creation of links to groups from other cultures. Groups with a high exclusion parameter are less connected with other cultures than the ones with a low exclusion parameter, as we discuss in the meso analysis of the following simulation experiments.

**Exclusive allocation** Groups only provide means to and receive means from groups with the same culture.

## 4 Simulation experiments

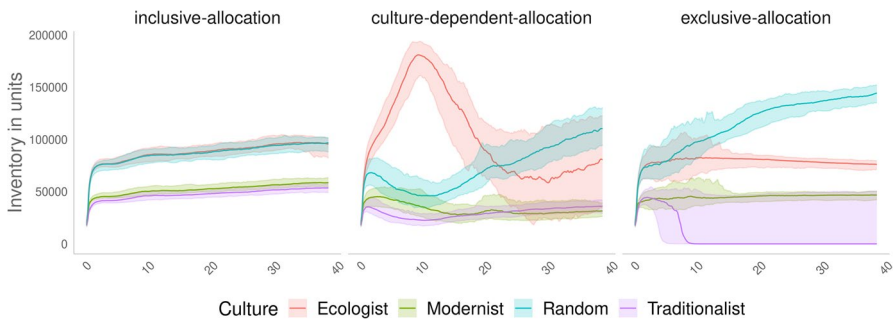
We conduct a series of simulation experiments to test different allocation mechanisms within COMMONSIM. In particular, we test the robustness of COMMONISM in the context of exclusion and inclusion between cultures, as aforementioned, coordination by (1) inclusive allocation, (2) culture-dependent allocation and (3) exclusive allocation. These three setups correspond to our baseline scenarios. On top of this, we test two different institutional mechanisms (common inventory, indirect reciprocity) for the case of exclusive allocation on their capacities to stabilise reproduction even in an exclusionary setting.

### 4.1 Experiment settings

All experiments and repetitions are initialised with the same amount of agents and groups, as well as with the same groups per culture (see [Appendix](#)), allowing for a minimal degree of control for comparison of results. The list of simulation experiments is summarised below.

- (1) Inclusive allocation: allocation of means between all groups, regardless of culture (base)
- (2) Culture-dependent allocation: allocation of means dependent on culture (base)
- (3) Exclusive allocation: allocation of means only within the own culture (base)
  - a. Allocation of means only within the own culture + common inventory
  - b. Allocation of means only within the own culture + indirect reciprocity

Each experiment was repeated 100 times with different random seeds to inform on the stochasticity of the model. Overall, we conducted 500 runs in total, each with 2000 turns/ticks (~40 years in simulated time). Simulated data is analysed on macro and meso scale. For the macro analysis, we show figures with aggregated time series



**Fig. 2** Culture-specific inventories, presented for scenarios (1) inclusive allocation (base)+(2) culture-dependent allocation (base)+(3) exclusive allocation (base)

for the 0.05, 0.5 (median) and 0.95 percentile. Weekly data is smoothed by a rolling quarterly average. The meso (disaggregated) analysis focuses on network data, in particular closeness centrality, drawn from certain discrete time steps.<sup>12</sup>

## 4.2 Baseline cases: a comparative discussion

The comparison of baseline cases is differentiated via a macro and a meso analysis of simulated data. The former indicates main aggregate indicators of the utopian economy and the latter highlights endogenous dynamics in the network structure of productive means groups.

### 4.2.1 Macro

From a macroeconomic perspective, the simulation of the commonist utopia allows us to study some aggregate measures of production and demand as well as cultural evolution. We first look at culture-specific inventories of productive means groups (PMGs), those groups producing intermediary and final means (Fig. 2). All cultures feature common culture-specific inventories that keep means as a buffer for the two most critical sectors of production, i.e. the resource sector and the first tier of production. The more primary the sector of production, the higher is the volatility in demand, making those two sectors the most vulnerable ones to abrupt changes in demand. In general, all inventories of PMGs are central for the group's signalling and planning processes; they determine the demand/planning upstream and function as group-specific buffers (see Section 3.3). After production, half of the groups' individual inventories are transferred to their culture-specific inventory, in order to stabilise production in precautionary terms for the two most critical sectors. First

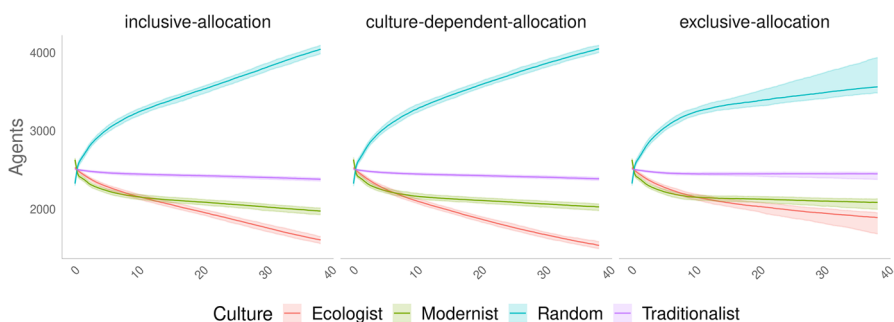
<sup>12</sup> See further parameter settings in the [Appendix](#). The simulation is implemented in NetLogo and available under GNU General Public Licence on COMSES, including documentation and ODD protocol (<https://doi.org/10.25937/jzk7-5q58>). Simulation experiments were conducted with NetLogo's internal "behavior space" tool and the generated data is aggregated and visualised with R.

experimentation with the simulation has shown that production, planning and coordination are not stable without those inventories in the artificial utopia. Activities in the inventories are moreover good indicators of production across the system as its volatilities are early signals for crises.

Figure 2 addresses this aspect with a view of all three baseline scenarios. Inventories are stable for inclusive allocation where all cultures provide means to each other in case of shortages. This changes once exclusion enters coordination (see exclusive allocation plot), as traditionalists cannot keep up production since their culture-specific inventory is already depleted after 10 years. The random cultural trait compensates for that loss in production, because even when traditionalists' production crashes, individual traditional agents are still alive and demand final means via their life groups. The culture-dependent allocation clearly makes an interesting case in terms of inventories. Ecologist groups increase their culture-specific inventory after 5 years and share intermediary means to the critical sectors of traditionalists (ecologists are the most altruistic ones), allowing them to dive through the first years of crisis. The sudden drop in ecos' inventory after 15–20 years is caused by a reordering of culture per group. Agents adapt to their group mentalities; on macro level, random culture crowds out ecologists thereby, as indicated in Fig. 3. Overall, under culture-dependent allocation, groups are able to keep up production across all cultures, but are less stable than under inclusive allocation.

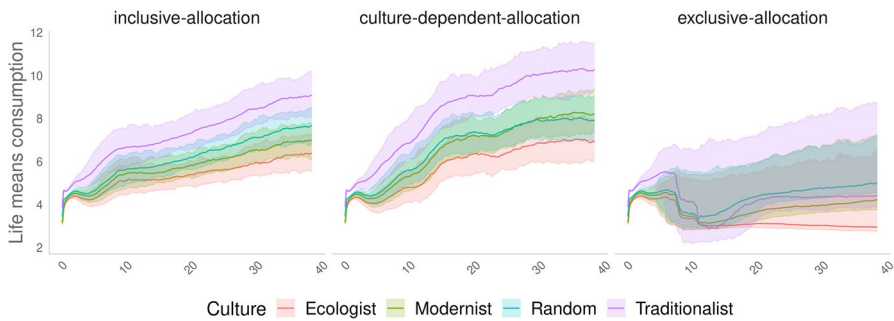
The random trait is the most adaptive and outnumbers the other traits over time. Most of the switching between cultural mentalities happens between random and eco traits. Cultural evolution is expressed through the adaptation of ego, eco, prod and leisure levels over time. These levels depend on the communication and adaptation between agents and PMGs, i.e. their social network. The ecologist trait is very open to other cultures (altruist) and builds up external connections under inclusive as well as culture-dependent allocation. Over time, this altruism backfires, as agents with eco trait get influenced by the traits in other groups, e.g. adapting to the random trait. To this extent, the random trait is significantly shaping cultural evolution in the artificial utopia.

Agents satisfy their sensual-vital needs with consumption, differing across cultural mentalities (see Fig. 4). Minimum consumption is set to three units per agent by default across all cultures. The maximum consumption per agent observed is about



**Fig. 3** Cultural evolution, presented for scenarios (1) inclusive allocation (base)+(2) culture-dependent allocation (base)+(3) exclusive allocation (base)

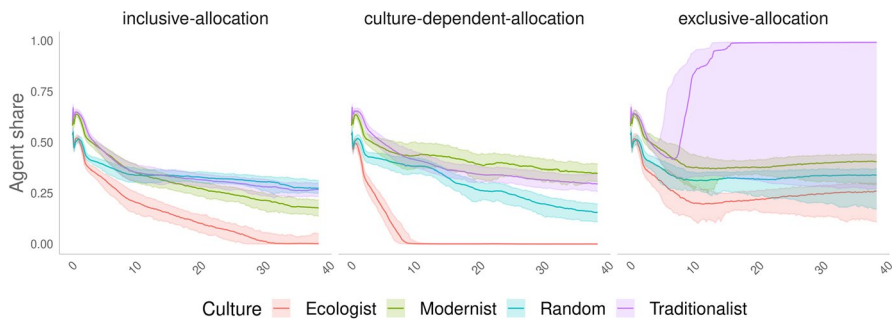




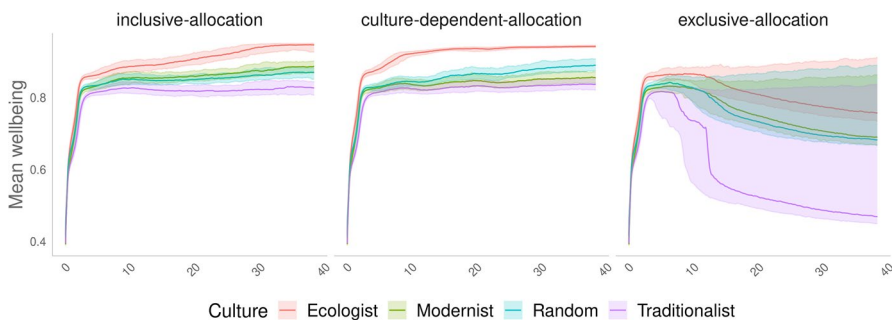
**Fig. 4** Effective demand, presented for scenarios (1) inclusive allocation (base)+(2) culture-dependent allocation (base)+(3) exclusive allocation (base)

three to four times the minimum level, for traditionalists under terms of cultural-dependent allocation. Effective demand (eventual consumption of agents) depends on production capacities, which are lowest under exclusive allocation, as groups may only draw additional machinery from their culture-dependent inventories. Production cannot expand under these terms; hence, consumption is endogenously limited and agents cannot realise their targeted consumption. On the contrary, under inclusive and culture-dependent allocation, agents get what they want, enabled through expanding consumption path, i.e. economic growth. In terms of culture, consumption of traditionalists grows the most, of ecologists the least. However, these heuristics drive traditionalists into crisis under exclusive allocation, as production capacities get depleted due to too quickly growing consumption. Traditionalists only meet their targets by freeriding on other cultures' production, as given under inclusive or culture-dependent allocation. One could assume that this freeriding behaviour of the traditionalists is exploitive and unjust because they acquire the means other agents produce while their contribution to the community is low or non-existent. However, the experiments show that under the absence of power to force others to work for on one's own sake, plus given the dependency on generally available goods, there is no possibility of accumulating means to dominate others. Moreover, the exclusive allocation scenario shows the highest variability of data (broadest ribbon), indicating low stability of the system. Consequently, in the long run, traditionalist's wellbeing decreases because their level of cooperation is too low to develop successfully. This shows that in a society free of domination, the ones that cooperate best prevail.

Keeping up production to meet agents' consumption targets demands agents to get involved in production groups. The share of agents not in production groups (Fig. 5) represents a kind of unemployment rate thereby, although the artificial utopia does not build on employment contracts and labour relations, as discussed in Section 2. Agents are free to leave and enter production groups within their culture. Under terms of inclusive allocation, this share decreases over time due to growing consumption targets. Productive means groups steadily increase the demand for agents participating in production. The highest share of active agents (thereby lowest share of agents not in production groups) is given by ecologists, because it is the trait with the lowest productivity per agent, vice versa



**Fig. 5** Share of agents not in production groups, presented for scenarios (1) inclusive allocation (base) + (2) culture-dependent allocation (base) + (3) exclusive allocation (base)

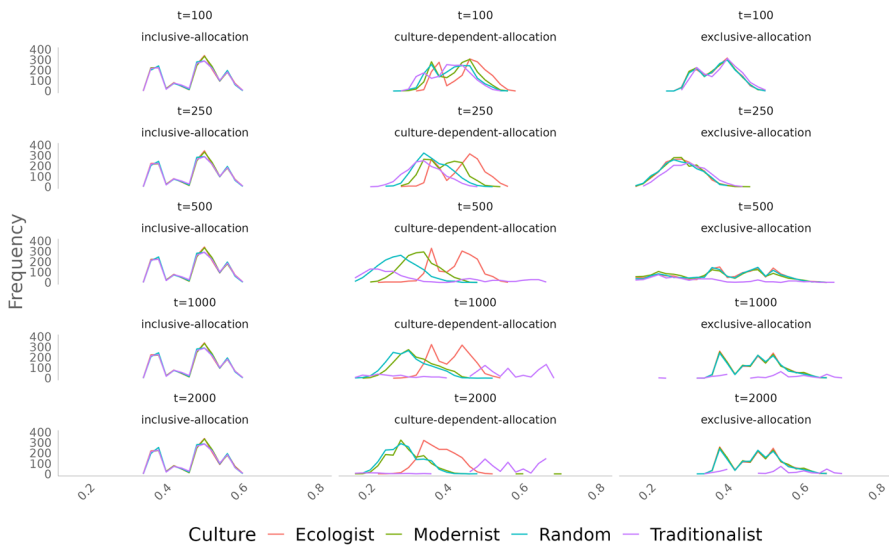


**Fig. 6** Wellbeing of agents, presented for scenarios (1) inclusive allocation (base) + (2) culture-dependent allocation (base) + (3) exclusive allocation (base)

for traditionalists. Under culture-dependent allocation, all eco agents are active in production groups already after 10 years, as ecos establish additional production links, especially for compensating consumption aspirations of traditionalists. Under terms of exclusive allocation, the crisis of traditionalists is reflected by all traditionalist agents being inactive in production groups. Otherwise, all other cultures have a steady development of the share of agents in production groups, because consumption is limited by exclusive allocation.

The wellbeing of agents per cultural trait represents the evolution of social welfare in the artificial utopia. It informs on the satisfaction of both types of needs, sensual-vital (is realised consumption meeting the agents' targets?) and productive needs (is realised productive activity meeting the agents' targets?). Figure 6 shows the wellbeing of agents per cultural trait for the three baseline cases.

Ecologists are best satisfied, traditionalists lowest, because of their higher ambitions/targets. Limited production and consumption under terms of exclusive allocation has a strong effect on agents' wellbeing for all cultures. Foremost, the wellbeing of traditionalists is in freefall due to their crisis in production, both types of needs cannot be satisfied. The other cultures experience a drop of 20% in wellbeing over time, a substantial loss. Eventually, inclusive allocation leads to



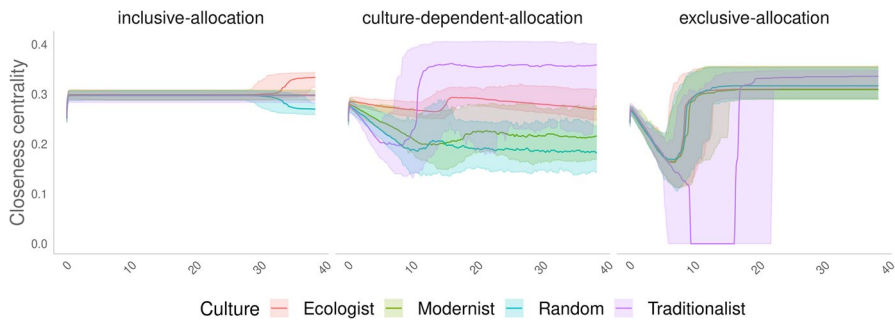
**Fig. 7** Closeness centrality, presented for scenarios (1) inclusive allocation (base)+(2) culture-dependent allocation (base)+(3) exclusive allocation (base)

the highest wellbeing in total across all cultures; maximum wellbeing is reached by ecos under terms of culture-dependent allocation.

#### 4.2.2 Meso

Production networks follow different path-dependent structuration processes dependent on allocation and coordination mechanisms. We take a meso perspective and look into the cumulative frequency of closeness centrality per culture in Fig. 7.

Closeness centrality is a normalised measure [0,1] for the average shortest path between a node and all other nodes. High closeness of a node means that the node is very closely connected to all other nodes. We compute closeness centrality for production groups and their connections to all other production groups, i.e. production links. Figure 7 indicates the cumulative frequency of closeness per group and culture over all repetitions. Each row shows the data of discrete moments of simulated time. The figure shows the frequency of nodes for each value of closeness centrality in the production network, across all repetitions per culture and experiment. The production network's structure stays the same under terms of inclusive allocation over time. Production networks build up immediately within and between cultures in this setting, enabling a stable reproduction of flows between groups. Under terms of exclusive allocation, we may follow the crisis of traditionalists' production also from a meso perspective. After 500 ticks, closeness centrality of traditionalists drops, signalling the collapse of the culture's production network. Otherwise, this crisis leads to the restructuration of other cultures' production networks after 1000 ticks, with two major peaks in the frequency of closeness (around 0.35 and 0.5), meaning that



**Fig. 8** Closeness centrality, presented for scenarios (1) inclusive allocation (base) + (2) culture-dependent allocation (base) + (3) exclusive allocation (base)

on average, half of the production groups are closely connected via central nodes and the others more loose. This is different under culture-dependent allocation, where closeness has a tendency towards a unimodal distribution over time for all cultures except traditionalists. The latter's production network depends on other cultures' production after 500 ticks. The decrease in the frequencies of traditionalists corresponds to the collapse of a share of traditionalist productive means groups.<sup>13</sup>

The remaining traditionalist groups are however very closely connected and central to the production network, as shown in Fig. 8 by the closeness centrality per culture over time. Furthermore, the complex evolution of the production network can be exemplified along a visualisation of a representative single run (see Fig. 9).

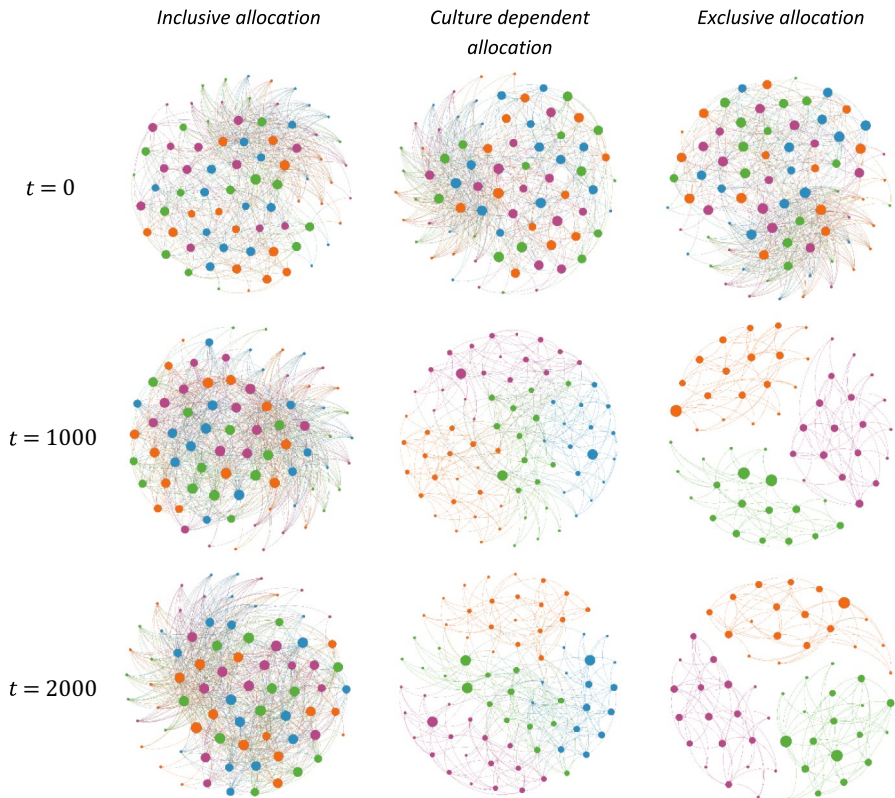
Under terms of exclusive allocation, the production network is already completely segregated per culture at  $t = 1000$ . Inclusive allocation demonstrates the opposite, productive means groups establish links within and between all cultures, and the whole artificial utopia becomes an integrated complex adaptive system. Culture-dependent allocation guarantees the establishment of weak links (Csermely 2009), bridging between cultures and keeping traditionalists' production alive.

### 4.3 Experiments: institutional mechanisms for exclusive allocation

The collapse of the traditionalist production under terms of exclusive allocation highlights a weak spot of the communist utopia. High ego and productivity values and higher aspirations for consumption make the production network collapse and indicate that even utopias may face difficulties with defective traits. Political enforcement of a change in those values may be misleading in such cases. To this extent, we test two institutional mechanisms on their capacities to compensate for the losses: (a) a common inventory across cultures and (b) indirect reciprocity as an endogenous institutional mechanism of cultural evolution.<sup>14</sup>

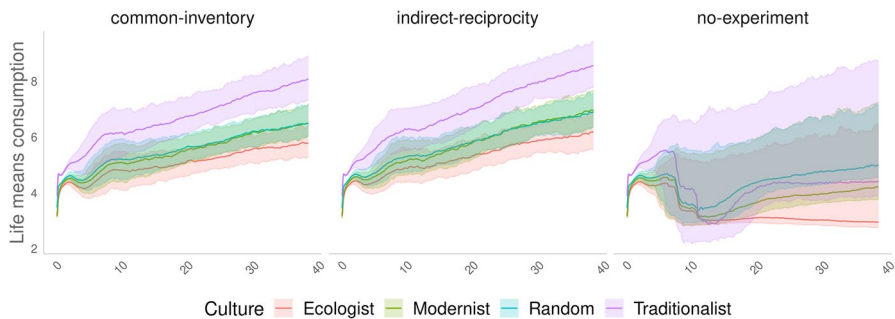
<sup>13</sup> Collapsed groups are groups that did not have any output over a period of 3 months. The groups are dissolved and the agents have to look for a new production group if they want to be active.

<sup>14</sup> See e.g. Nowak and Sigmund (2005).



**Fig. 9** Exemplary evolution of production network (colour represents the four cultures: magenta=modernists, orange=random, green=ecologist, blue=traditionalist; size of the production nodes increases with increasing closeness), presented for scenarios (1) inclusive allocation (base)+(2) culture-dependent allocation (base)+(3) exclusive allocation (base)

The common inventory stacks up a buffer for *means* from all cultures and provides those to the two critical sectors (ERGs and PMG1s) of all cultures on demand. Otherwise, indirect reciprocity allows productive means groups to seek support across cultures in the same sector. A group demanding additional means sends a signal to another group of another culture in the same sector. The contacted group decides to share its own intermediary means on two premises. First, own production targets have reached at least 90%, and second, the signalling group provides means to the other culture. If both conditions are met, this triangulation is activated and 10% of the production means are provided. If the support is denied due to culture, it increases the cooperation willingness of the demanding group. If a threshold is passed, more cultures are added to the possible cooperation partners.



**Fig. 10** Effective demand, presented for scenarios (3a) exclusive allocation + common inventory, (3b) exclusive allocation + indirect reciprocity, (3) exclusive allocation (base), i.e. no-experiment

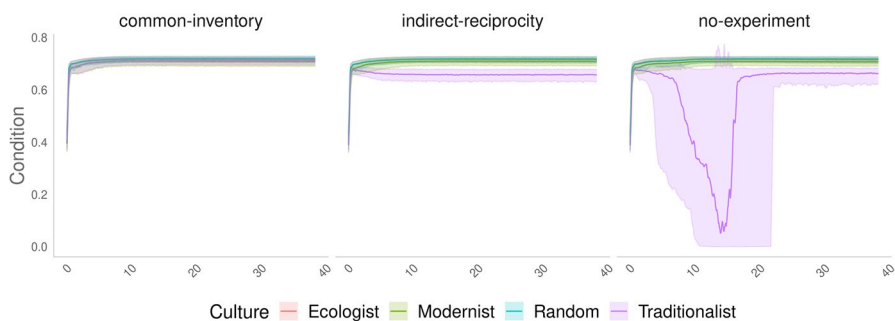
The indirect reciprocity mechanism facilitates a reaction to crisis based on group interaction. Groups are willing to support each other if they expect a favourable treatment of their own culture. This may induce a long-term change of norms and cooperation behaviour in cultural evolution.

#### 4.3.1 Macro

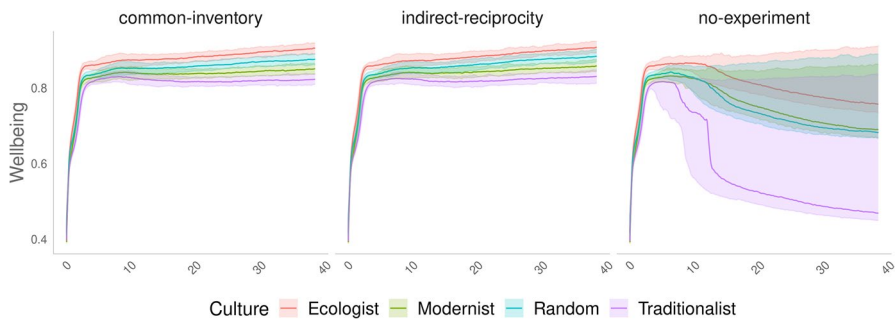
Both institutional mechanisms have the capacity to compensate the crisis in the traditionalist culture as can be shown along effective demand (see Fig. 10).

The condition of groups is better for all cultures with the common inventory, as the condition of traditionalist groups is slightly lower than the others in case of indirect reciprocity (Fig. 11).

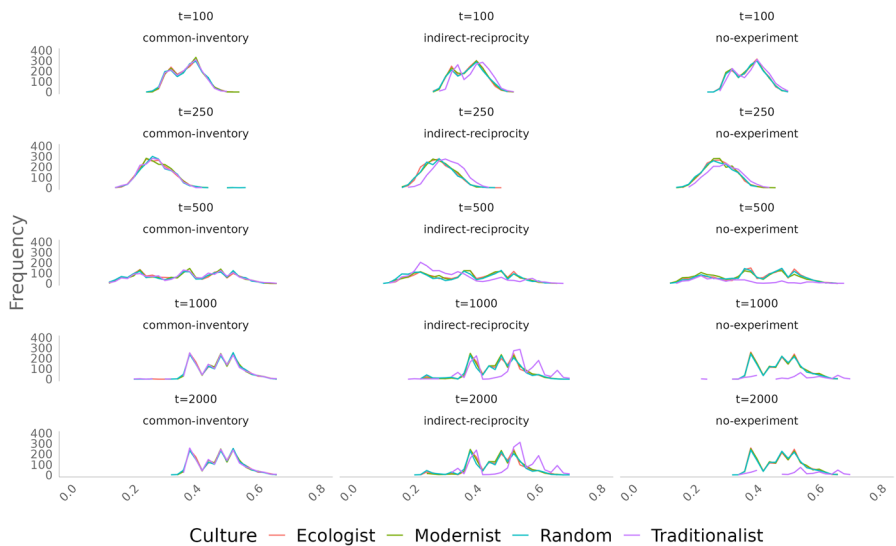
As highlighted in Section 4.2., in the baseline case (no-experiment), the condition of traditionalist groups recovers only because their productive means groups collapse; hence, the average condition of production groups goes up. However, in general, we cannot highlight any specific differences between the common inventory



**Fig. 11** Condition of groups, presented for scenarios (3a) exclusive allocation + common inventory, (3b) exclusive allocation + indirect reciprocity, (3) exclusive allocation (base), i.e. no-experiment



**Fig. 12** Wellbeing of agents, presented for scenarios (3a) exclusive allocation + common inventory, (3b) exclusive allocation + indirect reciprocity, (3) exclusive allocation (base), i.e. no-experiment



**Fig. 13** Closeness centrality, presented for scenarios (3a) exclusive allocation + common inventory, (3b) exclusive allocation + indirect reciprocity, (3) exclusive allocation (base), i.e. no-experiment

and indirect reciprocity experiment from a pure macro perspective, as further indicated by the aggregated wellbeing of agents (see Fig. 12).

#### 4.3.2 Meso

Different outcomes for the common inventory and indirect reciprocity mechanism are more explicit from a meso perspective. Figure 13 shows the production network's evolution for both mechanisms. The crisis in traditionalist production reshuffles the structure of the production network. Where the common inventory



**Table 2** Summary of main results

Experiment	Result
(1) Inclusive allocation: allocation of means between all groups, regardless of culture (base)	The inclusive allocation setting is the most stable one. All cultures cooperate, and the culture-specific inventories remain relatively stable throughout the whole simulation. The system is characterised by a highly connected network structure. Effective demand increases for all cultural groups, with traditionalists having a higher effective demand than the other cultures and ecologists the lowest. The number of agents active in productive groups increases for all cultural groups; most active are ecologist groups. The wellbeing remains stable and high for all
(2) Culture-dependent allocation: allocation of means dependent on culture (base)	The overall picture of this setting is similar to (1): Effective demand is increasing for all cultural groups in a similar vein, as is the number of agents active in productive groups. The wellbeing is at a high and stable level. The underlying structure however changed compared to (1). The network of productive groups becomes more segregated over time, with only weak links connecting the different cultures. These are however sufficiently stable to keep all cultures alive. The network of the traditionalist groups is slowly breaking apart and groups are vanishing, while the remaining ones are still functioning because they are supported by groups of other cultures (see closeness centrality in Fig. 7 and exemplary network structure in Fig. 9). This coverage by other groups is also indicated by more volatile and increased culture-specific inventories of random and ecologist groups
(3) Exclusive allocation: allocation of means only within the own culture (base)	The exclusive allocation setting leads to a system crisis, mostly however affecting traditionalist groups. The production network quickly segregates into the four different cultures, with no connections between them. The traditionalist culture cannot keep up production, due to higher demand, and their common inventory is depleted after 10 years. This leads to a deterioration, and finally vanishing of the traditionalist production network. Agents of the traditionalist culture are no longer active in productive groups; their effective demand drops, as well as their wellbeing. All other groups also experience crisis, however, manage to stay active. Consumption drops for all, wellbeing as well, not as strong as for the traditionalist agents though. Generally, the data shows a higher volatility, indicating the instability of the system
(3a) Allocation of means only within the own culture + common inventory	Both mechanisms ((3a) and (3b)) have the capacity to mitigate the crisis described in (3). Effective demand remains high and increases continuously for all cultural groups, as well as the condition of the groups and their overall wellbeing. The common inventory helps the struggling groups in times of crisis, regardless of their culture, and stabilises the system in the long run. This approach, however, requires all groups of all cultures to agree upon the new structure in political terms
(3b) Allocation of means only within the own culture + indirect reciprocity	While the effect of (3b) is very similar to (3a), the mechanisms behind are quite different. The mechanism of indirect reciprocity stabilises exclusive allocation without introducing novel structures. It involves signalling bilaterally between production groups of different cultures. A mutual triangle is only created for the time of the crisis, where intermediary means are provided to keep up the production and prevent collapse. The closeness centrality indicates that the traditionalist groups make the most use of this mechanism since their connectedness increases over time more than that of the other cultures

locks all cultures into the same network structure (in terms of closeness), indirect reciprocity enables a different path-dependent network evolution, with traditionalists having a more closely interconnected network after the crisis at  $t = 500$ . Traditionalists needed the most support from other groups and the crisis forced them to cooperate with other cultures.

Overall, the production networks are not altered by indirect reciprocity for a long time since the triangulated network extension via weak links is only of temporary nature. Once the shock of the crisis is dodged through provision of intermediary means by groups from other cultures, these links are disbanded and not needed in the long run. The mechanism of indirect reciprocity stabilises exclusive allocation without introduction of novel structures, in contrast to the common inventory where all groups of all cultures would need to agree upon the new structure in political terms. Indirect reciprocity involves signalling in a bilateral way between production groups of different cultures. A mutual triangle is only created for the time of the crisis, where intermediary means are provided to keep up the production and prevent collapse. All results are summarized below (Table 2).

## 5 Concluding remarks

As modern society faces multiple global crises, demands for social and economic science increase, to formulate, discuss and evaluate potential futures. While a growing number of alternatives are being put forward, few of these go beyond a social-ecologically regulated market economy or an updated state-socialism. The latter political economic conceptions match individual motivation and societal necessity by wage labour, build on extorted labour and distribution of wealth via money. Otherwise, political economies that decouple “giving” and “taking” at the individual level present a different provisioning system, linked to reciprocity, distribution via needs and motivation. Commonism, as presented by Sutterlütti and Meretz (2018; 2023), does just that, following critical psychology at the micro level, the theory of the commons at the meso level and the critique of political economy at the macro level. According to critical psychology, human beings seek agency in order to satisfy their sensual-vital needs. As societal beings, humans gain such agency only by participating in the societal process, by pursuing and satisfying their productive needs. In this respect, the economic model of *homo economicus*—isolated, work-averse and utility-maximising—is only a historically specific model of human nature, i.e. a capitalist model. In commonism, no central state (or polity in general) decides on the organisation and coordination of work or the allocation of means, but the commons do so themselves through various alliances and networks of cooperation. Planning is thus organised as iterative, evolutionary, decentralised self-organisation. Exchange value forces people to labour. In contrast, use value motivates people to work collectively according to productive needs. This reciprocity-based provisioning enables a logic of inclusion where factories have to organise

reproduction processes according to the needs of their workers and commons have to build mutual trust between and within groups over time to meet a diversity of needs, as cooperation cannot be bought. The utopia of commonism integrates institutional mechanisms of cultural evolution to stabilise cooperation on a large scale (Bowles and Gintis 2011), such as e.g. indirect reciprocity (Nowak and Sigmund 2005).

Agent-based modelling is an interesting method for utopian research, as it not only requires concretisation and specification but also allows the testing of large-scale alternative provisioning systems. In our simulation COMMONSIM, agents produce resources and sinks, as well as intermediate, care and final means, in life and production groups. These heterogeneous agents strive to satisfy their sensual-vital and productive needs, and depending on their experiences update their evaluations of their conditions (emotions) and priorities for different needs. Furthermore, the agents differ in a set of four personal characteristics: ego, influence by social networks; leisure, desired active time; eco, concern for the environment; and prod, output orientation. Based on these characteristics, four group cultures are formed (ecologist, modernist, traditionalist and random).

In a series of simulation experiments, we tested three allocation mechanisms over 100 iterations per scenario: (1) inclusive allocation (groups cooperate regardless of culture); (2) culture-dependent allocation (some groups will cooperate only with groups of their same culture); (3) exclusive allocation (groups only provide means to and receive means within their culture). The inclusive scenario leads to the most stable reproduction. Under exclusive allocation, cultures such as traditionalists face significant problems of reproduction, while culture-dependent allocation allows traditionalists to survive the first years of crisis, with the support of other cultures. To deal with the allocation problems of exclusive allocation, we tested two institutional mechanisms. The first mechanism introduces an element of centrality through a common inventory to which all groups contribute part of their production. The second mechanism introduces an element of decentralisation through indirect reciprocity. Here, groups provide means to groups of a different culture when they have largely achieved their targets and the other group also provides means to the giving group's culture. Both mechanisms can compensate for the crisis of traditionalist culture and lead to similar results at the macro level. At the meso level, the common inventory scenario locks all cultures into the same network structure, while indirect reciprocity temporarily stabilises traditionalist re/production via weak links, thereby diversifying the network structure.

With COMMONSIM, we simulate a simplified version of the utopia of COMMONISM. Simulation experiments have shown that the artificial society is able to reproduce itself even on a large scale, via mechanisms of polycentric planning, bottom-up signalling and self-organisation. To our knowledge, this is the first computational simulation of its kind, and it aims to stimulate further research on utopias using simulation approaches, in order to facilitate viable futures of the evolving political economy.

## Appendix. Parameters

Please see Tables 3, 4, 5, and 6.

**Table 3** Agent and environment parameter initialisation

System setup	Value	Variables used in equations
Population size (slider on interface)	10,000	
Number of ERGs (slider on interface)	12	
Number of ESGs (slider on interface)	8	
Number of PMGs per sector (slider on interface)	12	
Number of PMG sectors (slider on interface)	3	
Number of LMGs (slider on interface)	12	
Number of CMGs (slider on interface)	8	
Number of connections	3	
Initial level of culture inventories	100,000	
Waste rate of culture inventories	0.05	
<b>Environment</b>		
Initial level of pollution	0	
Initial level of sinks	50	
Sink productivity	1000	
Pollution multiplier	1	
<b>Agents</b>		
tcm minimum: minimum demand of transpersonal care means	4	$tcm_{\min}$
Initial demand of transpersonal care means	5	$tcm_{i,t0}^{\text{target}}$
icm minimum: minimum demand of interpersonal care means	20	$icm_{\min}$
Initial demand of interpersonal care means	21	$icm_{i,t0}^{\text{target}}$
lm minimum: minimum demand of life means	3	$lm_{\min}$
Initial demand of life means	5	$lm_{i,t0}^{\text{target}}$
Severity of care need	[0,1]	$w_{i,t}$
Probability for care need	0.07	$prob_1$
Link between care demand and time spent by agents	0.5	$ct_i$
Ego level	[0,1] (see Table 1)	$c_{i,t}^{\text{ego}}$
Leisure level	[0,1] (see Table 1)	$c_{i,t}^{\text{leisure}}$
Eco level	[0,1] (see Table 1)	$c_{i,t}^{\text{eco}}$
Productivity level	[0,1] (see Table 1)	$c_{i,t}^{\text{prod}}$
Characteristic trends of cultures	[0,1] (see Table 3)	$c_{\text{prg,trend}}^k \wedge c_{\text{lg,trend}}^k$
General adaption rate of agent-to-group values	0.2	$a_2$
General adaption rate of agent priorities for life and productive groups	0.05	$a_3$
Multiplier of severity of extra care demand	2	$a_1$

**Table 4** Characteristic trends of cultures

	Ego-trend	Leisure-trend	Eco-trend	Prod-trend
Ecologist culture	0.1	0.6	0.9	0.1
Traditionalist culture	0.9	0.1	0.1	0.9
Modernist culture	0.1	0.5	0.5	0.9
Random culture	[0,1]	[0,1]	[0,1]	[0,1]

**Table 5** Life group parameter initialisation

Life groups	
Group size	[2,10]
Agent productivity for production of one icm	1/7

**Table 6** Productive group parameter initialisation

Productive groups		ESG	ERG	PMG1	PMG2	PMG3	LMG	CMG
Agent productivity	$a_4^{sector}$	1	1.5	1.2	1	0.8	2.1	1
Productive means intensity	$a_5^{sector}$	1	1	1.6	1.6	1.6	2.5	2.5
Resource intensity	$a_6^{sector}$	-	-	0.7	-	-	-	-
Reserve target		-	0.6	0.8	0.6	0.2	0.2	0.2
Waste rate of inventory	$a_7^{sector}$	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Depreciation rate of productive means	$a_8^{sector}$	0.02	0.1	0.15	0.15	0.15	0.2	0.1
Pollution intensity		0.1	0.75	0.8	0.6	0.7	0.3	0.4
Absolute pollution intensity		1	100	1000	100	500	1	0.1
Sink intensity		-	1	-	-	-	-	-
Group size initialisation		~ 10	~ 10	~ 15	~ 35	~ 110	~ 90	~ 280
Total sector size initialised (number of groups $\times$ group size)		80	120	150	420	1320	1080	2240
Total agents in productive means sectors and care sector		3170						2240

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## Declarations

**Competing interests** The authors declare no competing interests.

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