

Energy, surplus and the economic process

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ABSTRACT

This paper analyses the economic process through the concept of surplus, combining insights from ecological economics, Marxist political economy and anthropology. Humans, we argue, appropriate surplus energy with their labor from nature and apply it to transform matter into goods and services, with entropy increasing along the way. How societies distribute and expend their surpluses gives them some of their signature features. In hierarchical societies, the ruling classes control a great share of the surplus and expend it in ways that reproduce their power. Economic growth, a distinctive feature of capitalist civilization, is the result of the ruling capitalist class investing surplus in the means of production in order to make more surplus. Surplus is extracted both via technological innovation that increases productivity and by social domination that reduces the share of surplus that goes back to workers or nature. Growth, however, is not only a material process but also a hegemonic story told by the capitalist class to dress its private interest as general interest, legitimating control over the destiny of surplus. Our framework proposes a political, ecological-economic theory of growth, provides a foundation for analyzing degrowth, and sheds new light on longstanding debates between ecological economists and Marxists.

1. Introduction

Ecological economics (EE) highlights how ecosystem stocks and flows sustain and limit human economies (Costanza et al., 1997; Daly and Farley, 2011). Developed as a critique of neoclassical economics, EE does not have its own theory of how capitalism works (Pirgmaier, 2021). EE has convincingly pointed to limits to growth (Murphy Jr, 2022), documenting how growth has become “uneconomic” (Daly, 2014), and making a case for post- or degrowth (Kallis et al., 2025), but it still lacks a theory of economic growth proper. Such theory cannot be based on mainstream accounts of growth, whose pre-paradigmatic

view is that growth is good. Here, drawing from a synthesis of energetics, Marxian political economy and anthropology, we revisit the economic process through the concept of surplus, offering an ecological economic foundation to theorize growth and degrowth.

We call this synthesis a “political ecological economics” (PolEE): an ecological economics informed by a broadly defined political ecology, building on the tradition of ‘the Barcelona school of ecological economics and political ecology’ (Villamayor-Tomas and Muradian, 2023).¹ If EE approaches human economies as a social metabolism, where people appropriate energy and apply it to transform organic and inorganic matter (Martinez-Alier, 2009), political ecology shows how

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¹ Berger (2008) was the first, to our knowledge, to use the term ‘political ecological economics’ to designate an integration of Kapp's theory of social costs with institutional economics and Dewey's pragmatism. Whereas Kapp's theory of cost-shifting is central to our framework here, our extension of ecological economics is not towards institutional economics, but towards Marxian political economy and anthropology: two lines of thought that form the bedrock of political ecology.

this metabolism is shaped by power along the lines of class, gender, ethnicity and race; a power that is also exercised through claims to knowledge and truth (Forsyth, 2004; Robbins, 2019; Sletto, 2008; Swyngedouw and Heynen, 2003). This paper completes a series of contributions where we looked at the economic ideas behind the case for degrowth, having found a mix of ecological economic, Marxian and anthropological sources (Kallis, 2017, 2018, 2023). In reverse, we formalize these concepts here as the political ecological economic foundations of the theory of degrowth.

With PolEE we do not wish to invent a fancy new term or establish a niche field. PolEE offers one possible – though not exclusive – foundation for EE at large. There is no desire, however, to convince everyone to do ecological economics like we do. The PolEE synthesis advanced here is also not the only one possible (see, for example, precursors in Hornborg, 2024; Martinez-Alier and O'Connor, 2002, and recent contributions by D'Alisa and Demaria, 2024; Pineault, 2022; Hickel and Kallis, 2020; Taşdemir Yaşın, 2023). We see our approach as part of the 'Social Ecological Economics' strand of ecological economics (Spash, 2011). A different referent for the type of EE developed here, however, is merited. Compared to Spash's social ecological economics, we rely on Marxist-feminist political economy and not institutional economics. Our PolEE embraces a soft constructionism that acknowledges how economic categories are themselves social inventions that shape the reality they describe, a constructivism which might not be fully compatible with critical realism, at least not in the way Spash presents it. Indeed, Robbins (2015) calls political ecology a 'trickster science', mobilizing as it does selectively realist and constructionist perspectives – for instance documenting scientifically the physical causes of land degradation, while deconstructing the value-laden schemes scientists use to classify lands as degraded. We are not interested here to debate the epistemological purity of this approach. If the 'trick' works and constructivist insights from anthropology offer some understanding of the economic growth process, which is our goal here, then this is good enough.

Our synthesis is centred on the notion of surplus, and is sketched first in Section 2.1. Section 2.2 brings in the EE insight that human economies are moved by energetic surpluses appropriated from nature, and that the efficiency with which such surpluses are captured and converted to final work determines the size of economic activity. From Marxist political economy, we then take the idea that those who own the means of production keep for themselves as large a part of the surplus as possible by pushing to the minimum what is given back to workers or spent to control pollution or to regenerate nature (Section 2.3). From anthropology, and Science and Technology studies (STS), we take the idea that uneven surplus distribution is mystified, legitimated, and orchestrated through powerful forms of knowledge and representation produced by the science of economics (Section 2.4). Section 2.5 brings these ideas together into a model of the economic process.

Section 3 uses this model to rethink the nature of economic growth, discuss limits to (green) growth and articulate degrowth differently than is often the case. Economic growth, we argue, involves investing surplus to make more surplus. Growth is hard to absolutely decouple from environmental damage since nature is a principal source of surplus. Degrowth involves a redistribution of surpluses away from growth, and towards serving working peoples' needs and towards repairing environments, while collectively spending the rest. Such a redistribution passes through a political struggle, including a struggle over scientific representations and associated institutions. Section 5 concludes, acknowledging loose ends around questions of technology and domination and trade and finance while outlining future research.

Integrating ecological economics and Marxist political economy might be less straightforward than we make it seem here, but we do not want to interrupt the flow of the narrative and overcomplicate the foundational theory offered by delving into scholastic differences that may disorient the general reader. In Appendix A, we focus on differences in underlying theories of value, a core sore point between ecological and Marxist economics (see Hornborg, 2022; Kallis and Swyngedouw, 2018;

Pirgmaier, 2017; Röpke, 2021), differences which we argue are not irreconcilable. Debates over energy, labour and surplus have a long history, which dates back to at least the 1880 essay of Ukrainian socialist Serhiy Podolinsky and its reception by Marx and Engels, the history and the significance of which have become a matter of dispute between Marxist and ecological economists (Foster and Burkett, 2004; Martinez-Alier et al., 2026). In Appendix B, we argue that the two approaches are not as unbridgeable as it may seem, if we revalue Podolinsky's original insight that labor captures energy surpluses that the capitalist class then appropriates, an insight that we argue has been validated by what we have learned since then. These two appendixes are standalone contributions to scholarly debate. Hopefully, they advance the PolEE synthesis advocated here and render the proposed theory of surplus more convincing to the sceptical expert.

2. Surplus and the economic process

2.1. A first approximation

We start with an idiosyncratic, to say the least, precursor of PolEE, Georges Bataille (Grimm, 2024; Romano, 2019; Schlaudt, 2025).² Against economic orthodoxy, Bataille claimed that the universal economic condition of humanity is one of excess not scarcity (Bataille, 2017 (1949); Romano, 2019). Bataille distinguished the restrictive economy of economic actors, where scarcity is the norm, from the general economy of planet Earth, where living systems receive more solar energy than is necessary for their reproduction. Surpluses accumulate on earth's surface, Bataille argued, ultimately squandered majestically or catastrophically (think of lush vegetation or fires as solar excess builds up in trees and plants).

Like other living systems, humanity too receives more energy than it needs for its mere reproduction (Fig. 1). This surplus must be spent eventually without return – in 'opulent feasts, war, art or an unproductive upper class' (Schlaudt, 2025); unproductive expenditures that Bataille denominated as 'depense' (Fig. 1). Investing in the means of production relieves temporarily the pressure for expenditure, Bataille argued, but it makes matters worse, as subsequent surplus grows and the pressure to ultimately spend it builds up.

Humans receive an influx of energetic surplus from the sun. A share of this surplus is used to reproduce the human economy – it goes to workers' subsistence, maintenance of the means of production, etc. Another part of the surplus can be invested in expanding the means of production, causing growth. A final part of the surplus is ultimately expended, out of circulation, without return.

Bataille is one of the earliest authors we know of who was interested in 'the prospects of an economy not centred on growth' (Bataille, cited in

² Georges Bataille (1897–1962) was a French intellectual working on eroticism, mysticism and transgression, known to the French public for his extremely erotic novels, and the rituals and orgies of his group, Acephale. Posthumously, he was appreciated as one of the most important post-structuralist philosophers. Bataille's work is hard to penetrate for the uninitiated. His celebration of Sade, human sacrifice, and occasionally violence makes his ethics in some instances hard to digest. What interests us here, however, following Romano (2019), is Bataille's concept of 'depense': unproductive surplus expenditure. This concept was central in Bataille's 'theory of the general economy', developed in the 1940s in a latter, more sober stage of his life. One can find there a unique combination of ecology and thermodynamics with the political economy of Marx and Keynes, alongside anthropologies of the rituals and spending practices of pre-capitalist societies. In his thermodynamics, Bataille was influenced by Vladimir Vernadsky and the prominent theories of Schrödinger, Auerbach and other scientists following the philosopher Bergson on the negentropic nature of life (Grimm, 2024). Schlaudt (2025) argues that Bataille's theory of the general economy offers a good macro-account of the economic process and a foundation for a 'strong energetics' approach in ecological economics.

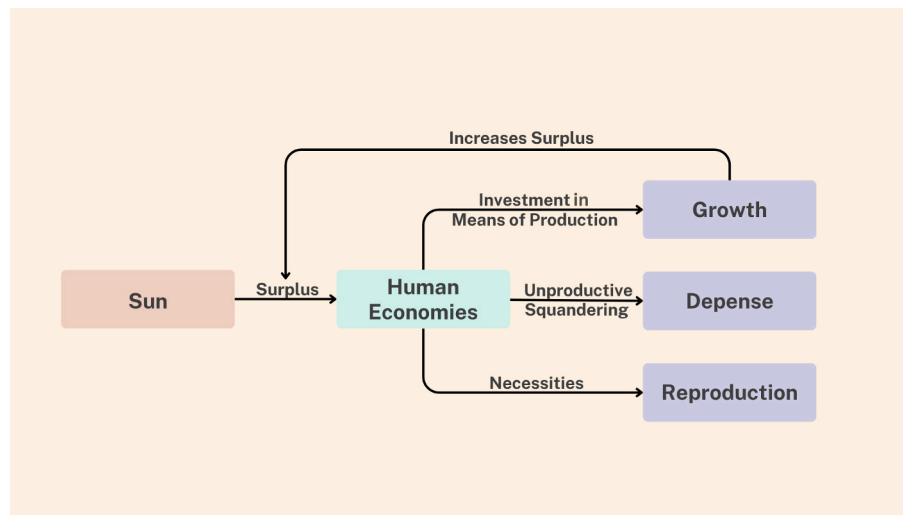


Fig. 1. Bataille's view of the economic process.

Romano, 2019, p.54). When growth eventually faces territorial limits, which it must, Bataille observed, then more than ever humans *must* squander, but this goes against their restrictive experience of scarcity, which is aggravated by the condition of limits. Expending the surplus is a source of existential angst, hence surplus is an 'accursed share' (the title of Bataille's book). Societies relieve this anxiety, always partially, with collective feasts or works of beauty and glory that give a sense of shared meaning and purpose – or when not, war and destruction take over.

Bataille was not an economist, but his theory, broad-brush and peculiar as it may be, is useful for conceptualizing the origins and destinations of surplus (Fig. 1). It also has obvious limitations. First, demarcating empirically reproduction and investment from depense is hard, as Bataille himself acknowledged. A cell phone, to give a contemporary example, may be a productive investment if used to coordinate a production process, or an unproductive depense if used to dance to music. Furthermore, many unproductive expenditures support power structures, which are then put to economic ends – consider for example the pyramids, and how they helped to solidify the power of pharaohs, a power then used to mobilize people for land-grabbing wars. Like other classificatory concepts, we note here that Bataille's distinction makes intuitive sense, but partially breaks down when confronted with complex realities. A more serious limitation for our purposes is, however, the treatment of surplus as manna from the sun. Humans, in fact, *must labor* and expend energy to capture excess solar energy. Ecological and Marxist economics can help here to grasp how precisely such 'social metabolism' works.

2.2. Energy and surplus in ecological economics

The economic process, ecological economics teaches, is a metabolic process where humans use their muscles and brains, burning 'endosomatic' calories to transform matter into a form that serves their needs. Humans augment their work with 'exosomatic' tools, like say tractors, fuelled by external sources of energy (Kallis, 2018; Martinez-Alier, 2009). All energy, suffice to say, except nuclear and tidal power, originates in the sun. Humans capture it through edible crops or animals, from the work they appropriate from draft or farm animals, by capturing solar and wind power, or by burning biomass and fossil fuels.

Ecological economists provide a conceptual toolkit to analyze the energetics of this metabolism. 'Net energy' refers to the energy surplus

of a society, i.e., the socially available energy that remains after accounting for the energy requirements of extracting, converting and delivering that energy (Delannoy and Murphy, 2026). If net energy measures how much energy surplus an economy has, i.e., an absolute quantity, EROI (the energy return on energy investment) measures surplus as a ratio, i.e., how large the energy obtained is relative to the energy invested in obtaining it (Hall et al., 2014). Net energy and EROI can be measured at the source (e.g., oil field), the point of delivery (e.g., gasoline station), or the point of use (e.g., the energy that moves a car) – each energy step from the source to the end use decreasing the measured EROI as energy is used or lost in the in-between stages.

If net energy analysis captures a core quantitative aspect of social metabolism, thermodynamics highlight its qualitative features. Georgescu-Roegen (1971) first argued that the economic process is entropic; heat is released, waste produced, and entropy (disorder) increases, as low-entropy resources are turned through extraction and production into high-entropy goods and wastes. Thermodynamics highlight the importance not only of energy surplus quantities, but also of energy quality, i.e., the capacity of a given surplus of energy to do useful work. 'Exergy' refers to the useful part of energy that can do work as a system reaches thermodynamic equilibrium with its surroundings - exergy diminishes through the economic process, mirroring the increase of entropy (Brockway et al., 2018). Exergy efficiency, the ratio of useful work obtained to the maximum possible useful work, measures how effectively a process captures the maximum work potential (exergy) of an energy source (e.g. gasoline) into actual work output (e.g., car movement). This efficiency, alongside the total quantity of 'useful exergy, provides relevant indicators of the productive potential of an economy. Research by Ayres and others, for example, has shown that useful exergy correlates strongly with total factor productivity and growth (Ayres and Warr, 2010; Sakai et al., 2018).

Whereas net energy is the physical surplus available to a society, and useful exergy the final work that can be done, 'emergy' captures the total energy previously spent by nature and society to generate that surplus, e. g., the tens of thousands of solar Joules gone to create one Joule of oil in geological time. (Emergy should be distinguished from 'embodied energy' which refers to shorter-term past inputs used in a production process - for example the energy embodied in a ton of steel is the energy that went into making this steel). Odum hypothesized that the higher the emergy of a product or energy source, the higher its ability to do useful

work (Brown and Ulgiati, 2004; Odum, 1988).

Not all energy resources contribute to surplus in the same way. Georgescu-Roegen distinguished between stock-flow resources, such as fossil fuels, and fund-flow resources, such as ecosystems, soils or labour that must be maintained to continuously reproduce the surplus of the economic process (Georgescu-Roegen, 1970). Stocks are finite and flows from them can be extracted at a chosen rate until the stocks are depleted. Flows, like solar and wind energy, are instead practically unlimited but provided at a rate determined by nature. Unlike stocks, funds like labor, land and infrastructure, are not consumed when used as they are replenished by flows. An economy's viability from this perspective depends on its ability to sustain its funds with its available low-entropy stocks and flows. Whereas earth is a system open to an unlimited low-entropy flow of solar energy, limited only by the land and vegetation capacity of earth to capture it, fossil fuels, an accumulated stock of solar flows, are finite and dissipate after use (i.e., the energy cost of reconcentrating their dissipated energy is prohibitively high), posing a potential limitation to economies dependent upon their use.

The main problem with fossil fuels, however, is not only their finitude, but that their emissions when burned threaten to irreversibly destabilize the climate. From an entropic perspective, waste and pollution are unavoidable features of any economic process: a share of the captured surplus is always dissipated as heat or degraded materials. Reducing pollution, in turn, requires investing a considerable share of final net energy in pollution control or ecosystem repair. The higher such 'exergy penalties' (da Silva Neves et al., 2026) are, the lower the *truly* net energy surplus available. Economies can and often do shift pollution to the future or to other parts of the world, reducing artificially the exergy penalty and increasing localized surplus in the short term, at the cost of damages elsewhere or further into the future. This pervasive incentive, especially for profit-driven business activity to shift waste and costs in space and time was first noted by Kapp (1970). Externalities, from Kapp's perspective, are not a corrigible 'error' of markets that can be internalized but a pervasive feature of any economic activity whose motive is the increase of surplus.

Having clarified the biophysical conditions under which surplus can be generated, we now turn to how this surplus is socially organized and distributed. Here basic concepts from the Marxian lexicon are indispensable.

2.3. Domination, exploitation and surplus in Marxian political economy

Social power controls metabolic flows and the distribution of surpluses (Swyngedouw, 2006). Conflicts between say indigenous groups and mining companies are, in fact, struggles between different ways of organizing social metabolism (Silva-Macher and Farrell, 2014). Marxist political economy/ecology offers a potent way to conceptualize power relations of domination and how they govern the distribution of surplus.

A good starting point here is Marx's theory of exploitation (Marx, 2024). Marx showed how the seemingly fair contract of the capitalist factory hides an underlying relationship of exploitation of workers who sell their labour to survive, by capitalists who own the means of production. Marx went to prove the existence of exploitation under the theoretical, fully-competitive (labor) market assumptions of political economists, where capitalists buy all factors of production, labour included, at the cost of their production. No capitalist sells a machine to another capitalist for less than it cost to produce it, and workers therefore are also paid, under conditions of perfect competition, the cost of their own reproduction. According to Marx's labor theory of value, market exchange reduces the (exchange) value of a commodity to the (relative) proportion of the total pool of salaried labor that is invested in producing it, or what in the Marxian jargon is called its socially necessary/average labor time (see Appendix A). The cost that capitalists pay workers is then equal to the socially average labor time that went into producing workers' food, clothing, shelter, education, etc. But capitalists get back the labour time workers endow to products, which must be

more than what is needed for the workers' reproduction, otherwise there would be no growth in production.

This extra that capitalists keep is *surplus value*. Surplus value can be extracted by extending the working day, encroaching on workers' rest and leisure time or by reducing the costs (labor time) of producing the basics needed for workers' reproduction. Importantly, capitalists are propelled to *maximize* surplus value and invest it to grow their surpluses and profits more, lest they want to be made extinct by market competition. Exploitation is therefore a systemic feature of capitalist economies.

Marx's account reveals an unequal exchange of labour time beneath a façade of fair money exchange. Marx focused on what was novel under capitalism: exploitation of nominally-free salaried workers who, unlike, say, slaves, willingly commit to a contract. Others, however, pointed to the extraction of surplus also from non-wage labourers, an extraction that may have preceded capitalism but continued under it and remained an important part of it, since without it, it is doubtful that capitalists could make the profits they make, or any profits at all. This includes surpluses from unpaid or underpaid carework, mostly done by women, or from the racialized foreign labour of initially slaves and then undocumented immigrants, maquiladora workers, miners or peasants in the Global South.³ Whether Marx foresaw, or theorized correctly in his labour theory of value, these unpaid 'subsidies' to capital is beyond the point here - recent feminist, decolonial and ecological updates of Marx's framework do conceptualize in useful ways these different forms of surplus-making (Barca, 2020; Harvey, 2014; Moore, 2015; Robinson, 2023; Taşdemir Yaşın, 2017).

Revisiting capitalism as an 'institutionalized social order' comparable to other orders like feudalism, Fraser (2023), for example, offers a useful classificatory distinction between exploitation taking place within the realm of what tends to be seen as the economic proper (i.e., the realm of money-based exchange), and processes of *appropriation* and *expropriation*, which are thought of as outside the economy but are, in fact, fundamental for the economy (Fraser, 2023). *Exploitation* is the extraction of surplus from wage labour under conditions of voluntary contract and is supposed to cover the costs of workers' reproduction.⁴ *Appropriation* refers to surplus making from unpaid or underpaid forms of work, such as carework or nature's work, that are taking place irrespective of capital (a mother would still give birth and care for her child), and which capital treats as 'free gifts', lowering what it has to pay back to workers.⁵ *Expropriation* denotes the forcible seizure of the labour

³ From a Marxist labour theory of value perspective, these other, unpaid sources of surplus do not have 'value', i.e., value for capital, as capitalists appropriate them for free, as 'gifts of nature'. Let us note, however, that although they do not have 'value' in the strict sense of Marx's definition of value, i.e., value from the perspective of capital, which means value created by wage labour (see Appendix A), they do affect 'surplus value', i.e., the surplus extracted from wage labour. Unpaid carework or a forest cleaning a city's air reduce the value of commodities wage workers need to consume for their reproduction. (Imagine if one had to pay for a domestic helper or for filters to clean the air of a city or a house). They therefore increase, indirectly, surplus value. A different channel through which nature may affect surplus value is through productivity. Higher EROI fossil fuels, for example, increase the productivity of wage labour and what in Marxist jargon is denominated as 'relative surplus value' (as distinct from the absolute surplus value, which is derived from the labor time of wage workers).

⁴ 'Super-exploitation', at the extreme end of things, takes place when labour is paid below its costs of reproduction, such as in the 'Satanic mills' of early capitalism, where workers, including children, would be exhausted to premature death, i.e., not being 'reproduced'. Fraser conflates in some instances super-exploitation with expropriation.

⁵ The classification of carework as 'appropriation' is debatable, as radical feminists contend that the work of women in families should not be treated as a natural, 'labour of love', passively appropriated by the capitalist economy, but as socially coerced through violence and patriarchal institutions (Federici, 2020). Carework, from this reading, has attributes of 'expropriation'.

of populations outside the wage system, usually through coercion, violence, or legal subjugation - for example, slavery, indigenous dispossession, wars and colonization, privatizations through structural adjustment, etc. Unlike one-off theft, surplus from expropriation is funnelled back into production. To Fraser's arch-types, one might add also surplus by *cost-shifting*, where capitalists profit by shifting pollution and other costs of the production process to marginalized groups, the population at large or future generations (D'Alisa and Demaria, 2024).⁶ Cost-shifting can be thought of as a source of surplus-making to the extent that it is a way to avoid dedicating the share of the surplus necessary to repay what we called, 'the exergy penalty'.

Exploitation, appropriation, expropriation and cost-shifting are different forms of how a ruling class, in the case of capitalism capitalists, draws surplus by *dominating* other classes. The 'political system' (Fraser, 2023) that we typically call 'the state', controls a share of surplus via taxation, which it dispenses in ways that may favour the ruling class, though not always or exclusively - social expenditures and the welfare state, for example, distribute a share of surplus to the benefit of working classes. The taxed share on the other hand may also fund military power, which in turn can be used to expand domination geographically and extract surplus from other parts of the world. There is a long history of imperial states financing military expansion with surpluses expropriated from such expansion (Arrighi, 1994, 2009; Hornborg, 2024), continued today under arrangements of unequal exchange between the periphery and the core of the capitalist order (Hickel et al., 2021, 2024).

Earlier attempts to integrate energetics and Marxian political economy - most notably Podolsky's - anticipated the questions addressed in this paper, because the historical reconstruction interrupts the analytical flow, we discuss these separately in Appendix B. Here let us recap what we learn from Ecological and Marxist economics in their current, mature form, and as presented in this and the previous section. From ecological economics we appreciated that the original source of all surpluses, what we can call *physical surplus*, corresponds to the net solar surplus extracted from nature (with qualifications captured by concepts like 'exergy', 'emergy' and 'entropy'). Marxian political economy in turn shows how it is workers who extract and apply this surplus to matter to produce goods, and therefore an important share of the net energy surplus is needed to reproduce the workers themselves. The ruling class, in the case of capitalism those who own privately the means of production, tries to keep as large a share of the surplus for itself, minimizing what goes back to workers or used to control pollution or replenish nature. When net energy surplus is unevenly distributed during production between the dominant/ruling and dominated classes, we say that a society is hierarchical, the upper echelons defined in fact by their power to control a larger share of the surplus. Indeed, the core feature of egalitarian hunter-gather societies was precisely the prohibition of the accumulation of surplus by individuals or classes, and its collective control and expenditure in feasts and rituals (Graeber, 2004; Woodburn, 1982).

Why and how do workers in capitalist and other hierarchically-organized societies, however, acquiesce, as they often do, in the unequal distribution of surplus? Physical violence and the monopoly of the

means of coercion by states, and by proxy ruling elites when they have privileged access to the political system, partially explain this. But anthropology offers additional insights into how power operates, including through consent and by forms of representation that make the dominated interiorize their domination.

2.4. Power, knowledge and surplus in anthropology

Documenting the myriad ways in which humans have organized themselves over millennia, anthropologists help contextualize the historical production of categories we tend to take for granted today, including 'the economy'. No doubt, humans must always provide for their needs or deal with their surpluses. There is nothing universal, however, in doing so by trading commodities for money, and nothing natural in partitioning - and governing - reality through categories like 'production', 'consumption', 'exchange', or 'distribution'. Other societies, for example, organized acts thought today as instances of economic 'exchange', 'distribution' or 'consumption' through social institutions or rituals that had little to do with 'the economy' - say potlaches, sacrifices or games. In Melanesian and Polynesian societies, for example, surpluses, embodied in non-necessary valuables, circulated through complex rituals, gifted often without expectation of return (Mauss, 2016). Gifts changed hands between individuals or communities, on some occasions ritually destroyed at the end of a cycle, returned to a nature thought of as providing them as a gift (Mauss, 2016).

Let us then specify here three insights from anthropology that can enrich our understanding of the nature of surplus. The first is that the expenditure of surplus is a locus of social meaning (and power). Revisiting ethnographic accounts, Bataille (2017) (1949) sketched the different ways historical formations expended their surpluses: the Melanesians in gifts and potlaches; the Egyptians in pyramids; the Aztecs in human sacrifices; the Tibetans in supporting a non-productive class of monks; early Islam in holy wars; Medieval Christianity to a clergy and to cathedrals; Protestants to saving and investing; the Soviets to breakneck industrialization and armament to defend against the Nazis.

One might disagree with Bataille's empirical details or find some of his claims exaggerated or impressionistic, but a point remains: there is a great variation in how societies expend their surplus, and this variation defines, to a certain extent at least, the essence of these societies and how they are remembered. Not only the type of spending signifies the identity a society builds for itself, but around the expenditure of surplus positions, ranks and social structures form. Vice versa, it is often the case that the rituals of surplus expenditure serve to symbolize and naturalize such positions and structures. Aztec merchants, for example, would sacrifice their human loot conspicuously in large feasts on returning home from expeditions, and modern capitalists assert their position in the social hierarchy by their ability to squander in acts of conspicuous consumption such as big yachts or phantasmagorical villas and parties (Bataille, 2017; Veblen, 2005). Likewise, in other societies, classes of monks, clergy, or rentiers express and reproduce their power, by not having to work manually in production and by the privilege of being sustained by the toil of others. Power one might argue, is precisely the ability to control surplus and especially to spend it unproductively.

The second insight from anthropology is that 'the economy', the way we come to understand the term today, is a relatively recent invention (Latouche, 2012) that, in our terms, organizes and legitimates the distribution of surplus under the capitalist social order. As Polanyi (1971) argued, 'the economy' is not a field of experience about which human beings have always been conscious. It is one that started taking shape during liberalism's 19th century 'great transformation', when labour, land (nature) and money itself began to be increasingly traded in markets for money, shaping the realm of the economic (Polanyi, 2001). In that era of 'political economy', however, the word economy still maintained its earlier meaning of economizing. The idea of *the* (national) economy, a noun referring to a separate entity governed by its own laws,

⁶ An alternative to Fraser's system is that of David Harvey who has distinguished between accumulation via economic means, i.e., wage-based exploitation, and 'accumulation by dispossession', closer to what Fraser would call expropriation, whereby capital separates people, often violently, from their means of subsistence or reproduction. This accumulation by extra-economic means (laws, policing or outright violence) was thought to be an original phase in capitalism, as in the enclosures that preceded industrialization, but Harvey, among many others following in the footsteps of Rosa Luxemburg, have shown that this is a continuing process that is necessary to sustain capital accumulation, especially when it encounters limits. D'Alisa and Demaria (2024), cited above, connect Harvey's theory to ecological economics, showing how cost-shifting via externalizing pollution is, in effect, a mechanism of 'accumulation by contamination'.

emerges as late as the 1930s (Mitchell, 2014). STS scholars connect the emergence of this new object of interest to the modern science of economics. Economists developed the tools - GDP, national accounts or models - that constructed 'the economy' by representing and measuring it (Mitchell, 2014). The representations of economists responded to the needs of new state institutions (ministries, statistical agencies, councils of advisers) and state functions (taxation, credit, monetary policy) that emerged in the context of the Great Depression, and the Second World and Cold Wars, and as governments increased their control over surplus by socializing production and taxing private activity. 'The economy' became the framework under which surplus was distributed to capitalists for growth, but also to workers for social stability, and to armies for war.

The third insight concerns how representations like those of 'the economy' operate as sources of power. Economists defined 'the economy' in ways that marked the boundaries between what counts as economic, value-creating activity and what not (Fraser, 2023; Waring, 1999), a choice that was political and had distributive implications. Fraser (2023) explains, for example, how the non-inclusion of women's care work in national accounts delegated such work to the undervalued household sphere from where it could be seen as 'naturally' appropriated; women receiving a much lower share of a nation's income than corresponded to their work. Others have shown the political battles between progressives and conservatives over whether to count non-market, public sector activity in GDP or to account only for private business activity (Coyle, 2015; Lepenies, 2016). Whereas the public sector's contribution was included (since otherwise military expenditures would not count as GDP), women's contribution was left out. 'The economy' is therefore not just a neutral, scientific representation, but one that is politically shaped, and actively so, in ways that legitimate certain distributions of surplus between different producers - in this case between women care workers, the army and capitalists.

'The economy', Mitchell (2014) further argues, became a new domain of 'governmentality', or 'economy' in the post-war era, i. e., a form of governing operating not through laws and force, but through techniques and knowledges that shape the "conduct of conduct", in this case techniques of economics. The proposition here is that economic representations and institutions help create reality in their own image, shaping how individuals conduct themselves within the system they find themselves in. Workers would accept, for example, lower wages in collective bargaining, interiorizing, for example, the need of the national economy to grow so that they can find a job. In another example, consider how many women interiorized their roles as 'housewives', accepting that what they do is a labor of love that is 'an insult to be compensated for', in line with the national accounts that left care work out of the economic sphere (see (Federici, 2020; Waring, 1999)).

From anthropology, then, we take the observations that surplus is a locus of power and meaning, and that 'economic' institutions and representations serve to naturalize and stabilize the distribution of surplus. Economic representations, in other words, create a cognitive and social environment which ensures that the ruled acquiesce to their own exploitation.

2.5. Surplus and the economic process, a proposed scheme

Fig. 2 elaborates Fig. 1 with core insights from ecological and Marxian economics (the anthropological contribution is harder to capture within the same graph and will be narrated further down).

Humans with their work capture physical surplus from primary (solar) energy, including energy embodied in plants and animals. They apply this physical surplus - i. e., the net captured energy after the energy costs of extracting it - to produce the necessities that ensure their own (human) reproduction. What remains after the share lost to entropy is an *economic surplus*, which can be either spent without return (depense) or reinvested to make more physical or economic surplus.

Surplus can increase in two ways: by innovation and by domination. Mainstream economics focusses on the first, more benign set of options: innovating and improving the productivity of the means of production (Fig. 2) to expend less energy in the performance of a task (or perform more with a given quantity of energy). Energy-process innovations can increase the 'exergy efficiency' or EROI of energy extraction and delivery, increasing physical surpluses. Production innovations can improve the efficiency in the conversion of a given quantity of energy/work to final goods and services. Consider the invention of the wheel; it reduced friction and reduced the energy lost as heat in transporting goods and people. With the same amount of energy, one could transport more objects/people, faster and further. This exergy efficiency gain can be thought of as physical surplus. One can distinguish here between real increases in *productiveness*, i. e., doing more with a given amount of work/energy, as in the case of the wheel, and what is called 'labour productivity', which may simply involve the substitution of human by non-human energy, as, say, in the case of human farm labour substituted by animal-powered or fossil fuel-based agriculture (Ashford and Shakespeare, 1999). Real productiveness can increase by inventing new physical 'technologies', i. e., artefacts like the wheel, or say robots, which improve exergy efficiency and get more work out of a given quantity of energy. These technologies are physical embodiments of human knowledge, and science and research play an important role here. Productiveness can also increase by improving what economists call 'human capital', i. e., the capacity of workers to do things as they accumulate knowledge, training and skills. And finally, productiveness can increase by improving 'social organization', such as specialization and social division of labour; instead of everyone doing a little bit of everything, each specializes in specific tasks that they can do faster.

The second broad way of increasing surpluses is, however, by intensifying domination, i. e., by exploitation, appropriation, expropriation or cost-shifting (Fig. 2). Surplus here increases by decreasing the share of surplus spent for necessary production, i. e., for the reproductive needs of workers, non-humans and ecosystems. The less surplus goes to workers and nature, the more remains as economic surplus (and the less the surplus that goes to energy workers or to regenerating energy extraction sites, the more the physical surplus). Unpaid carbon debts, for example, that can be seen as an exergy penalty, are a way to shift costs temporally and increase physical and economic surpluses in the short term. What may appear also to a society in capitalism's core (i. e. in the US or the EU) as a surplus, may be a debt if extracted through unequal exchange or super-exploitation of the periphery. Indeed, shifted costs constitute unpaid debts - not only ecological in the strict sense, but historical and social debts owed by the colonizers to the colonized (Da Silva, 2022).

Economic surplus can be directed to improving the means of production or towards intensifying domination (e. g., investing in policing, means of violence and control, propaganda, etc.). When effective, these investments may further increase surplus. The other outlet is depense, that is, unproductive expenditure, privatized or collective, constructive or destructive.⁷ As noted, the line between depense and reproduction may be blurry - for example, workers, especially in the imperial core, and in the post-war period of growing surpluses were paid more than basic reproduction for forms of privatized depense (e. g., vacations/holidays) that are deemed necessities today.

A final part of the model consists of the socio-political mechanisms of distributing surplus between the ruling class and the working people, a distribution intermediated by the political system (in egalitarian

⁷ Not captured in Fig. 2 is the fact that the production of unproductive expenditures (say concerts or monuments) is also subject to processes of innovation and domination and of redistribution of surplus, where one share goes to the final good/expenditure, say the monument, one is lost to entropy, and one remains as economic surplus to those who own the means that produced the monument, etc.

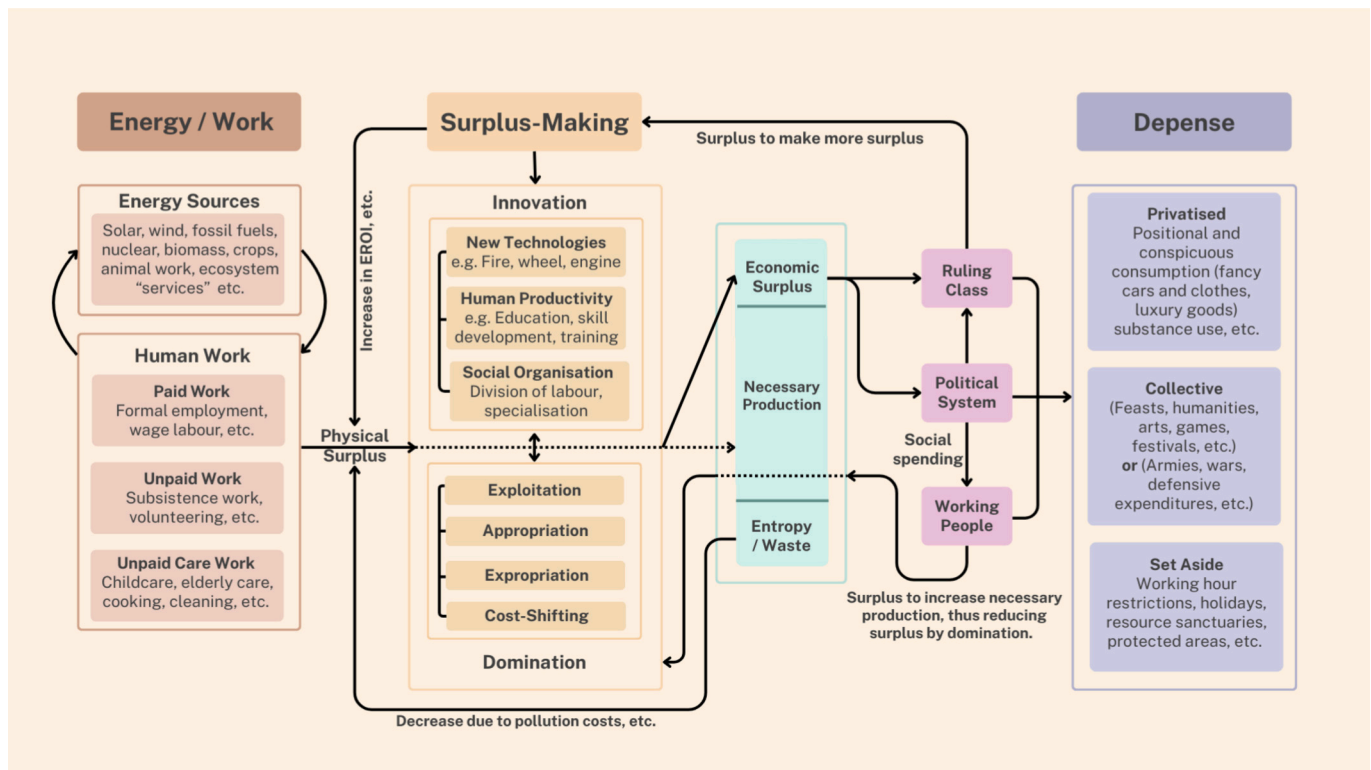


Fig. 2. Surplus and the economic process.

societies, where working people in theory directly rule themselves, this tri-partite division collapses into one). The ruling class, pressed by competition and the need to spend surplus in ways that reproduce its position, strives to accrue as much of the economic surplus as possible. The state collects a share through taxes or own production that it can direct to the ruling class, or to working people. For the working people, the goal is their reproduction (if possible, at better standards), and their ability to sovereignly expend a share of the surplus themselves.

In this framework, therefore, *physical surplus* (net energy) provides the material possibility of an economy, while *economic surplus* (what remains after subsistence and ecological repair) is the social reality that is contested, partitioned into privatized and social shares (which we may call *private* and *social surplus*), and eventually either reinvested, used to augment subsistence/repair or unproductively expended.

Physical surplus, i.e., the net energy surplus drawn out from nature by human work, is applied to produce the necessary goods and services that reproduce humans. Waste and entropy are produced along the way and reduce the real surplus available. What remains over and above necessary production and waste/entropy is economic surplus and can be increased by innovation and/or domination. When a share of surplus is invested back to innovation and domination, growth of surplus is the result. When a share of the surplus is devoted to basic production or to protecting/regenerating ecosystems, then exploitation, appropriation, or cost-shifting may be reduced. A substantial share of surplus is dissipated into various forms of final expenditures (depense): privatized, collective and foregone, some socially beneficial, others potentially destructive. To the extent that the ruling class controls the political system, surpluses become private surpluses and are directed to more surpluses or to elite depense. To the extent that the working class can claim power through the political system, surpluses become social surplus and through social spending are directed to necessary production (reproduction and regeneration) and/or to more collective depense.

3. Growth and degrowth revisited

3.1. Surplus and economic growth

Growth can be defined as an increase in the total work (labour and energy) mobilized to transform matter into goods and services; it is enabled by the reinvestment of economic surplus, expanding a society's productive capacity over time. Reinvesting surplus to the means of production or domination (Fig. 2) increases spare productive capacity and enables society to mobilize even more surplus in subsequent cycles, resulting in sustained growth. For example, if a farming society produces more food calories than needed for the subsistence of farmers, it can feed surplus labor which can build irrigation systems, producing more food, and capturing more solar calories from crops.

In neoclassical economics, increases in the factors of production face diminishing returns, and sustained growth can only result from increases in productivity. In Solow's model, growth is attributed to an exogenous 'total factor productivity' residual, a proxy for technological progress, whereas endogenous growth theories by Romer and others, highlight factors like innovation, knowledge, research and development, education and human capital, social organization and institutions, etc. (Jones and Vollrath, 2013). Econometric studies have apportioned growth to each of these attributes (Jones and Vollrath, 2013). This, however, covers only the mechanisms that in Fig. 2's terms we called surplus by innovation.

Mainstream theories are mute on the contributions of net energy, exergy efficiency or of domination, cost-shifting and unequal exchange to economic growth. Ecological economists have documented the link between exergy and total factor productivity (Ayres and Warr, 2010), and have measured the minimum societal EROI necessary for growth (Fizaine and Court, 2016; Hall et al., 2009). There are no equivalent studies, however, of domination and how it contributes to growth. There are, on the other hand, several historical accounts on the role of slavery, colonialism and the subjugation of women in the industrial revolution and in early economic growth (e.g., Beckert, 2017; Federici, 2009) and

new empirical computations showing how neocolonial relations still sustain today unequal exchanges of labor and resources without which growth in the Global North would not be possible (Hickel et al., 2021).

As in mainstream theories, growth in our account is supply-determined; unless there is surplus capacity, there can be no increase in economic activity. With constrained capacity, increase in demand for one activity can be satisfied only by reducing another activity. As in post-Keynesian theories, however, growing demand/expenditure in our model can 'cause' growth if it triggers investment to energy extraction or the means of production, increasing surplus and meeting the new demand without suppressing other activities. Conversely, when the supply of available resources far exceeds the demand, there is the need to devise new meaningful outlets to expend, or even squander such resources, otherwise as Bataille intuited, the surplus piles up and seeks release; or what in more proper Marxian economic terms is called a crisis of over-accumulation, with the risk of capital devaluation (Harvey, 2014).

An account of how growth happens, such as that in Fig. 2, needs to be complemented with a theory of the social functions it serves. Anthropology and STS here are relevant. Returning to the studies that we presented before by Mitchell and others, a core insight is that the notion of continuous, year-after-year economic growth appears for the first time with the invention of 'the economy' in the 1930s. Economists had previously talked of *increases* in population, agricultural produce, manufactures or riches, increases, however, that were thought to be cyclical, not compound. With the construction of "the national economy," represented by GDP, growth of the *whole* economy could now be conceptualized. The GDP aggregate, however, as we explained, hid the unequal relations producing it; and was imbued with the property of potentially limitless increase, since nothing in its constitution suggested limits (Mitchell, 2014). The function of growth was, as Mitchell claims, to bring 'the future into the present'. Making the future both calculable and, supposedly by nature bigger, helped to adjudicate distribution conflicts between capitalists and workers by promising workers a better future tomorrow (Mitchell, 2014). The expectations also of a stable and wealthier future allowed the construction of financial assets in the present out of hypothetical future production (Mitchell, 2026).

Following Fraser, we can identify different phases of capitalism, and different types and functions of growth in each phase (Table 1). Growth was a material reality under mercantile and industrial capitalism, but it was for the first time conceptualized and measured as GDP under state-based capitalism, a progressive political move it must be said under Roosevelt's New Deal, relating to government efforts to reign over private activity and share part of surplus with workers to keep social peace and economic stability. From the 1970s, and as a regressive redistribution starts under financialized capitalism (Fraser, 2023), the prominent function of growth became that of an ideological 'alibi of capital' (Mitchell, 2026).

How this alibi worked in practice has been extensively documented in the urban studies literature. In US cities, the notion of growth functioned as an organizing ideology through which coalitions of developers, bankers and businesspeople promoted their interests (Molotch, 1976, 1993). When in control of local administrations, such coalitions removed regulations that threatened profits and diverted social surplus to investments that supported real estate development, such as sports stadiums and mega-events, beautification and gentrification works, infrastructures, like roads, public transport or utilities extensions to peripheral areas, re-districting and tax-breaks to develop certain zones, etc. Growth in these contexts became a vehicle for hegemony (Schmelzer, 2016): i.e., the frame through which the ruling class could claim that it represents the general interest, while serving its own. In other instances, as Akbulut (2019) shows in the case of Turkey, growth provided the ideological glue legitimating processes of nation-building, while disguising how these processes primarily served the interests of the country's ruling elites.

3.2. Limits to (green) growth

In our model growth happens when surplus is reinvested to make more surplus. It follows that growth can continue only if surplus keeps expanding.⁸ Limits in turn emerge if this expansion is constrained. One possible source of limits is ecological constraints to surplus extraction. As energy systems expand to more marginal sources of energy, it is likely that EROI and eventually net energy, decline. The verdict as to whether we are on such a path is still open; early studies pointed to declining EROI for fossil fuels and low EROI for renewables (Hall et al., 2014; Murphy and Hall, 2010), but recent studies, accounting for advances in renewable technologies and comparing EROIs at the point of delivery (where renewables score better since they produce energy closer to use than fossil fuels) suggest that renewables may have superior EROI to fossil fuels (Brockway et al., 2019). Renewables, however, face limitations in terms of critical materials and land requirements, so the verdict on whether they can keep expanding and for how long remains open.

On the pollution side, soil degradation, biodiversity loss or climate change can also reduce the surplus available to the economy (Fig. 2). Beyond limits to growth, transgressing such 'planetary boundaries' is important in and of itself given the impacts it may have on the survival of humans and non-human species. One core debate here concerns the possibility of genuinely green growth, or 'absolute decoupling' i.e., continued economic growth with rapidly declining environmental impact, sufficiently fast to keep humanity within safe boundaries (Hickel and Kallis, 2020; Kallis et al., 2025). In our terms, this would mean increasing energy surplus while simultaneously reducing, first, its fossil fuel content, and second, the environmental impacts from the materials this energy surplus transforms.

Substitution of materials may indeed reduce environmental impacts. But substitution has limits: once cleaner materials and processes are widely adopted, and limits are reached in substitution, further growth in energy surplus will, in principle, extract and transform more matter, and total material throughput will grow (Ward et al., 2016). Substitution of fossil fuels by cleaner energy sources can sustain high – and even growing – energy surpluses while carbon emissions decline, but a separate issue concerns the secondary impacts of clean energy via land use, material extraction or, in the case of nuclear power, accidents and waste disposal. An important consideration also is whether there is true substitution or merely clean energies add-on on top of fossil fuels without phasing them out (Fressoz, 2024; York, 2012). A practical test is whether true substitution is happening fast enough, and the empirical evidence for carbon emissions suggests that it is not (Vogel and Hickel, 2023).

Technological innovation can increase exergy efficiency, allowing more useful work to be drawn from a given amount of energy. However, in the framework of Fig. 2, efficiency improvements increase surplus and therefore lead to more growth, and more energy use and associated impacts down the line. This corresponds to the well-known Jevons paradox (Alcott et al., 2012; York and McGee, 2016), reframed here in terms of surplus: efficiency improvements often lead to increased total energy use because the resulting surplus stimulates new activities.

⁸ The only other possibility here is a growth of the monetized expression of the economy (GDP) without actual physical surplus growing, e.g., through strategies of increasing the monetary supply, commodifying and charging for resources and goods that were previously accessed for free, etc. While increasing the money supply may stimulate growth in the short term, in the long term a decoupling of money from the physical resources it can mobilize leads to inflationary pressures and cannot be a strategy for sustained growth. Commodification likewise may increase the amount of work and energy spent now to access previously free-access goods, but this work and energy will be taken from somewhere else; unless, that is, surplus capacity grows, or more precisely, unless the desire to access the commodified resources/goods spurs activity and investment that increases surplus capacity.

Table 1
Growth regimes in different phases of capitalism.

Regimes of capitalist growth	Source of energy surplus	Exploitation	Carework/Unpaid Work Appropriation	Expropriation
Mercantile (16th - 18th century)	Human and animal muscles with rudimentary wind, solar, and hydro	Limited wage labour	Peasant, subsistence, and female home labour	Slavery and war plunder
Industrial (19th - mid-20th century)	Coal	Factory labour	Super-appropriated carework of women also super-exploited in factories	Imperial extraction
State-based (1945–1970s)	Oil, Coal	Unionized, welfare-state labour	Welfare-state mediated care	Neo-colonial extraction
Financialized (1970s to today)	Intensified fossil fuel extraction alongside nuclear power and new renewables	Precarious, and increasingly exploited labour	Debt-financed and racialised carework	Debt, structural adjustments and trade-based unequal exchange

Summary of [Fraser's \(2023\)](#) characterization of different historical regimes of capitalist growth, from the perspective of the Global North. Entries should not be read as if previous forms of exploitation, appropriation or expropriation are abandoned when new forms emerge as dominant; different forms can coexist for long periods of time and in different geographies.

Unless the surplus created by efficiency gains is redirected away from the means of production, efficiency tends to reinforce growth rather than reduce environmental pressures.

Our model points also to a certain kind of social limits to growth. Growth has historically proceeded by intensifying the exploitation of wage labor, the appropriation of care work or the appropriation of underpaid foreign labour through immigration, colonization or unequal exchange. Such strategies may compensate in the short term for resource limitations, but they cannot expand indefinitely; they face political resistance, moral and social contestation and geopolitical limits. They can indeed be reversed and therefore limit growth in the colonial centres that have benefited from them.

In sum, the window for green and inclusive growth is very thin as it would require simultaneously expanding energy surpluses, sustained efficiency improvements and substitutions, all in a context of decreasing, not increasing, domination and cost-shifting. Even in the best of cases where short term green growth materializes, in the long-run and given absolute physical limits to substitution and efficiency, limitless green growth is untenable. The alternative then is a redistribution and redirection of surplus away from further accumulation and towards basic needs, ecosystem regeneration and collective enjoyment - the perspective explored by degrowth.

3.3. Contribution to degrowth

Approaching degrowth as a redistribution of surplus is a different entry point than framing degrowth as a quantitative reduction of production/consumption or of footprints. Degrowth can be defined here as a process of ending exploitation, expropriation and most forms of appropriation and cost-shifting,⁹ while democratically controlling the remaining economic-cum-social surplus directing it to improve standards of reproduction, regenerate ecosystems, and collectively celebrate with the rest. From this perspective the objective is not just to use fewer resources, since savings can fuel growth, but instead to discover benign or reparative ways of spending surplus ([Romano, 2019](#)). An intentional redistribution of surplus to people, non-humans, nature and depense will bring growth to an end, as surplus will not go to the means of production ([Figs. 2, 3](#)). Degrowth, however, should be distinguished

from a scenario of 'capitalism without growth', whereby surplus growth is constrained by physical or innovation limits, and the ruling class maintains or grows its share of the surplus by intensifying processes of domination and cost-shifting.

Our PolEE synthesis makes three contributions to the current degrowth literature. First, we offer a shared ecological economics foundation to position and relate the different 'sources of degrowth': early 'decroissance' deconstructions of the 'invention of the economy'; culturalist-anthropological critiques of utilitarianism, including Bataille's; bioeconomic insights on entropy, and limits to growth; and 'justice' perspectives critical of social domination ([Demaria et al., 2013](#)). Linking these sources to ongoing intellectual traditions, such as energetics, Marxism and STS sharpens, we hope, the theoretical bases of degrowth research.

Second, our model offers a basic frame to start thinking systematically about the politics of degrowth and the role of science and scientists in these. [Fig. 2](#) indicates that where surplus is directed is ultimately a political question of power. Various movements of working people (labour, environmental, feminist, anti-colonial) may challenge growth coalitions to reclaim and redirect surpluses. How they may win in specific world-system conjunctures is an important research and political question. This political struggle over surplus is linked to a knowledge struggle. Growth, we argued drawing from anthropology and STS, functions as a hegemonic ideology that helps evade political/distributional conflicts around the destiny of surplus, posing its perpetual investment to the means of production as natural and inevitable. Alternative representations of the economic process, therefore, like [Fig. 2](#), can be thought of as part of 'boundary struggles' ([Fraser, 2023](#)), struggles over redrawing or collapsing the boundaries between the economic and the social, and what counts as valuable and what not in the existing social order. Scholars working for a 'new economics' may be thought of as the bearers of new representations. To produce, however, new, degrowth-oriented economies one needs to develop not only alternative representations and metrics, but also institutions fit for their times, like it happened after the Great Depression. The history of (economic) science and technology teaches us that the battle for scientific ideas is interconnected with political and social battles informed or inspired by these ideas.

Third, our framework allows the opportunity to engage productively with debates between Marxist and ecological economists in relation to degrowth. One core argument of Marxists sceptical of degrowth is that the real issue is capital accumulation, not growth, and that growth is a problem only under capitalism, not under socialism, which could direct growth to ends beneficial for working people, and not the ruling classes. To begin with, [Fig. 2](#) applies to any type of human economy – capitalist or socialist, growing or not growing. In feudalist economies, for example, growth was rare, because, our hypothesis is, surplus, as in most pre-capitalist social orders, was not invested to make more surplus but dissipated symbolically (or destructively) by the ruling feudal elites to

⁹ We say 'most', because some appropriation of energy surpluses will still be necessary in any human economy, downscaled as it may be. A degree of cost-shifting is also inevitable given the entropic nature of the economic process. [Fraser's \(2023\)](#), for example, ambition to restore and replenish all gifts of nature that are currently appropriated for free is a laudable one, but there are differences between funds, flows and stocks. While funds (land, forests, etc.) can and should be regenerated, stocks (like fossil fuels or minerals) cannot. And while, for some, flows like services from land, forests or rivers, is important to regenerate them, for others, like solar energy, this is not necessary.

reproduce their own position (Bataille, 2017). The innovation of capitalism was that the new ruling class invested a greater share of surplus to science, research and developing the means of production, which alongside novel, or uninhibited, forms of domination, produced unparalleled rates of economic growth.

Compared to capitalism, and in the terms of Fig. 2, under socialist orders, all, or most, of the surplus is controlled by the political system. If the surplus is directed into making more surplus, however, economic growth will be the result there too, and the fact that the surplus is socially controlled does not change that (Kallis, 2019).¹⁰ On the other hand, a socialist economy that redirects surplus away from technology and domination and into reproduction and regeneration, will most likely 'degrow' (Kallis, 2019), and indeed the term 'ecosocialist degrowth' has been used to distinguish between degrowth-oriented and growth-oriented versions of socialism (Kallis and D'Alisa, 2025).

In this respect, it might be useful to distinguish capital(ist) accumulation from economic growth. Somewhat oversimplifying, we can say that economic growth is a broader process that includes the reinvestment of both private and social surplus, while capital accumulation involves the reinvestment of private economic surplus only. Under capitalism, competition among private capitals makes the growth of private surplus an imperative; in this context, the political system can support the conditions for capital accumulation with social surplus, economic growth acting both as a material and ideological stabilizer. On the other hand, it must be acknowledged that to the extent that national defence, and offense, and national position and control of resources in the world-system depend on comparative growth, growth imperatives might extend beyond capitalist orders. Indeed, in the context of first, the Second World War, and then the Cold War, the Soviet economy set for itself growth targets, including a 150% within a decade growth goal in 1961 (Schmelzer, 2016). To conclude: economic growth is historically a product of capitalism and is the ideology that legitimates the unequal distribution of surplus under capitalism, but there is nothing automatic suggesting that non-capitalist systems will not reproduce similarly problematic growth patterns, unless they explicitly govern surpluses so as not to.

4. Loose ends and further research

This paper hinted at an audacious proposition: that the economic ideas behind the theory of degrowth, formalized here as PoLEE, can help conceptualize not only the costs or the limits, but also the *origins and causes* of economic growth. Whereas ecological economics is limited by taking neoclassical economics as its reference point (Pirgmaier, 2021), the degrowth literature is limited by not having its own explanation of its nemesis: growth. This paper has hopefully offered an ecological economic foundation to theorizing growth and degrowth. A focus on energetic and socio-political aspects of surplus offers, we argued, a foundation to synthesise ecological economics, Marxian political economy and anthropology, and to articulate the processes through which human societies draw, control, distribute, and expend surpluses, as well as the institutions and representations they use to justify and give meaning to their choices. From this perspective, growth is not simply good up to a point, after which it may become uneconomic (Daly, 2014): domination is the Janus face of innovation, and the benefits of growth,

at all levels, may be accrued for some by shifting costs to others and to future generations.

One loose end in this framework concerns precisely the links between innovation and domination. Hornborg (2024), for example, claims that the new technologies of the industrial revolution would never have been profitable without the super-exploitation and expropriation of labour from the colonies, through slavery and trade. Are such links between new technologies and new, intensified forms of domination *necessary*, historically specific, or merely coincidental driven by the search of capital for maximum profit? If technology is by necessity linked to domination, where does this leave technologically advanced societies? Is non-domination impossible unless we shift to very low-tech social arrangements? This is a strong claim that few, if any, critics of capitalism make, but then again, there is little thought given to different technological arrangements not resting on domination (for an exception, see Kostakis and Seitanidis, 2026).

A related question concerns the links between different geopolitical arrangements, technologies, sources of energy, and forms of domination. Fraser, for instance, suggests that in distinct epochs new forms of domination and energy appropriation emerge to resolve the limits capital accumulation and economic growth encountered (Table 1). For example, state capitalism's organization of care labour within the nuclear family (with the institution of the male breadwinner and the family wage), was a response to the exhaustion of the reproduction of the working class under industrial capitalism, where women and children toiled in the factories. Is there, however, an overriding factor, say energy or technology, shaping other forms of domination and leading to epochal transitions? Does exhaustion of surplus in one realm lead to more intensive extraction in another? When, and under what conditions, does extra surplus in one realm reduce exploitation in another (say fossil fuels allowing the end of slavery or child labour)? And are we entering a terminal phase of surplus exhaustion due to climate change or other net energy or innovation limitations?

A second loose end concerns questions around trade and finance. Theories of unequal exchange show how 'free trade' is a set of institutions that facilitate (and disguise) the extraction of labour and resources from the periphery to the benefit of the imperialist/capitalist core (Hickel et al., 2021; Hornborg, 1998). Nations that control trade flows appropriate a significant part of the surplus embedded in the goods traded. It is not a coincidence that the Genoese and the Dutch, the first dominant powers of the capitalist world system (Arrighi, 1994), produced little themselves, but laid claim to huge surpluses passing through their hands via maritime trade. An urgent question is how current shifts in international relations can alter the geographical distribution of energy and labor surpluses.

Financialization is the process by which financial actors, markets, and logics increasingly shape economic activity, enabling the extraction of surplus through credit, debt, and asset ownership rather than through direct production of goods and services. Ecological economists have largely neglected finance (for exceptions see Mayumi and Renner, 2023), distinguishing as they do between the real economy of social metabolism and the fictional economy of finance (Kallis et al., 2009). This somewhat normative approach, however, cannot *explain* important economic facts, such as the accelerated financialization of housing, land, sports, arts, or law; it can only normatively dismiss them as fictional and 'wrong'. Financialization, however, like all social fictions does shape social metabolisms materially: for example, in housing, asset financialization increases vacancy and hence construction, mobilizing energy and materials that would otherwise not be extracted (Kaika and Ruggiero, 2024). How to analyze links between financialized assets and metabolic or energy flows remains unresolved.

Timothy Mitchell's (2026) latest work opens new ground here: Mitchell dismisses the separation between a real and a financialized economy and shows how financial assets, a feature of capitalism from its very onset, are in fact a claim on future material processes, organizing extraction and domination now. Interest charged on a loan acts as a

¹⁰ One may argue that, in a truly democratic socialist system, the workers will be fully represented by their political system, and therefore any surplus out of workers' labour kept by the state will not be 'exploitation', a category applying only to the capitalist system (Vergara-Camus, 2019). This became a lively debate within socialist countries in the 1930S-50s, critics claiming that patterns of exploitation (and unequal exchange) were reproduced, with a new (non-inheritable) elite of bureaucrats emerging around the control of social surplus. Defenders of the regimes claimed that exploitation was, by definition, a non-issue under socialism (Martinet, 1971).

claim on future energy and work; it is an appropriation of future surplus that makes the immediate and continued production of that surplus a systemic necessity. Growth, in this light, is the process and representation necessary for stabilizing that ever-increasing production of surplus.

In addition to the above, our account could be developed in three different directions:

1. Macroeconomic models simulate degrowth policies and trajectories with neoclassical or Post-Keynesian dynamics. What would models inspired by Fig. 2 look like? Could Input-Output or other energy and labour accounting schemes be used to quantify and model the extraction, re-investment and dissipation of energetic surpluses (see, for example, Giampietro et al., 2011)? Could we simulate/assess degrowth policies, such as working-hour reductions or a job guarantee in relation to their effects upon exploitation, appropriation, and innovation? Could we quantify the implications of redistribution of surpluses upon growth itself and upon the well-being of different populations and ecosystems? Or of the effects of different energy transition scenarios on surplus production and distribution?

2. Mainstream econometric research has quantified the causal effects of technology, human capital or institutions upon growth. There are no efforts yet that quantify how net energy or processes of cost-shifting, exploitation, appropriation and expropriation of labour may be causally interacting and contributing to growth (or not). These should be developed.

3. Political research could revisit the question of growth coalitions and the ways they organize to turn cities, regions, nations, and world regions into machines of ever-expanding surplus extraction. Working people's 'anti-growth' coalitions need studying too where and when they emerge, given important divisions among working people along lines of class, race, ethnicity or gender, that are exploited by capitalists to sustain domination. When and how powerful coalitions of movements, unions and parties may emerge across differences, take power and survive the backlash, effectively re-channelling surpluses, are important questions that studies of movement-parties for example can shed light on (Holt, 2025). How and what type of action research can inform such 'anti-growth' coalitions is a critical practical question.

Appendix A. Value theory in ecological and Marxist economics

Marx distinguished between use value, value and exchange value. For example, if the use value of a blanket is the warmth it provides, its value is the socially average, abstract labor time it took to produce it, and its exchange value in, say, bread terms, is the number of loaves with the same amount of labor time that it would exchange for or, in money terms, say, 20 Euros. Money serves as the equivalent form of labor time embodied in commodities, functioning as iron pieces do in an old-school scale to weight (this does not mean that banknotes or credit cards embody the same labor time as the goods they buy, but that newer forms of money have come to represent older forms of money, like, say, gold, which, the argument goes, *did have* a correspondence in labor time with the goods for which they were exchanged. See Kay, 1979).

The labor time at stake is not only the time it took to produce the blanket, but also the "dead labor" embodied in the machines used to produce the blanket. The labor time that determines value is also not the specific time taken to produce this or that blanket, but the socially necessary or average time of producing blankets, meaning the average in the market labour time necessary to produce that kind of blanket under average conditions of production. Marx was working with the assumptions of (mainstream) political economists that he wanted to criticize, whereby competition pushes exchange to a market equilibrium; in such equilibrium a firm that produces above the average cost will lose to competitors and be driven out of the market. The adjective 'abstract' is also used before socially average labour time in the Marxist lexicon, meaning that in market exchange one unit of labor is exchanged for another independently of the specificities of each labor, in a pool of salaried labor. Marx showed how even under such idealized, perfectly competitive market conditions, what seems a fair deal between capitalists and workers, each committing to a voluntary contract, is anything but, since capitalists get more (abstract, socially average, dead and living) labor time from the workers than the labor time they give back.

Marxists are clear that exchange values is not the same as prices (and surplus value is not equal to profits), since markets are not in reality perfect and conditions, such as monopoly, demand effects, etc., make prices fluctuate above or below their exchange values. Suffice it to say here that the fact that the labor time (expended and especially dead and embedded labour time) of different commodities is impossible to calculate is not a reason to discard the hypothesis of exploitation offered by Marx. No other economic theory passes the test on being founded on measurable and empirically

CRediT authorship contribution statement

Giorgos Kallis: Writing, Editing, Conceptualization. **Claudio Cattaneo:** Writing – review & editing. **Angelos Varvarousis:** Writing – review & editing. **Marula Tsagkari:** Writing – review & editing. **Marta Conde:** Writing – review & editing. **Giacomo D'Alisa:** Writing – review & editing. **Ksenija Hanaček:** Writing – review & editing. **Borja Nogué-Alguero:** Writing – review & editing. **Filka Sekulova:** Writing – review & editing. **Aljoša Slamersak:** Writing – review & editing.

Declaration of competing interest

None.

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verifiable first value principles, as there is no way to measure the value of commodities independently of their prices. So, the labour theory of value can be considered as a theoretical construct upon which a broader edifice rests.

Importantly, Marx's edifice is not one that purports to explain the workings of each and every human economy; it is one that specifically applies to, and is meant as a critique of, capitalism. Those less familiar with Marx's work may think of his labour theory of value as a general claim on the nature of economic value; a misconception that is common among ecological economists. This is wrong, since Marx's theory was concerned with what is valued *in capitalist economies*, i.e., what capital values, not what is, or should be, value from a general moral perspective. The Marxian argument is not that economic value in general is equal to labor time, but that market exchange under capitalist relations reduces the value of everything into its socially average, abstract labor time. Marx's analytical categories are accordingly developed from the point of view of capital, not from first principles. So, when one reads a statement such as 'nature has no value', this does not mean that nature does not, or should not, have value. Rather, it means that, from the point of view of a capitalist who accesses nature for free, it *indeed has no value*. As Kay (1979) helpfully notes, this may appear as an inverted consciousness of the world as it is now, but it is, in fact, a true consciousness of a world that is itself inverted (p.19). Ecological economics reveal the distorted consciousness of neoclassical economics in its representation of the economy and the environment; Marxist political economy takes instead as its starting point capitalist economies as they are, with their distorted representation and treatment of the environment.

If Marxists take a shot on a theory of value under capitalism, ecological economists have largely stayed out of this task, confined to showing the distorted value system of markets and capitalism, where, say, the labor of a speculator or a social media influencer is considered as many times more valuable than the work of a farmer or of an end-of-life caretaker. Ecological economics hence provides a normative critique of value under capitalism, but not an explanation of how and why exchange values or prices are the way they are. Ecological economists have offered strong proposals about alternative systems of valuation, and plural 'value-articulating institutions' (Vatn, 2026), where incommensurable but weakly comparable values (Martinez-Alier et al., 1998) can be weighed in for valuation purposes. We do not find this incompatible with Marx's theory of value, which acknowledged the plurality and incommensurability of use (in the broad sense) values, but argued that it is market exchange under capitalism that commensurates all these weakly comparable use values down to their common denominator: socially average abstract labor time.

Now, ecological economists may also reject the thesis that value is reduced under market exchange to socially necessary labor time, but they do not propose either a clear alternative explanation of how value and prices form, other than broad allusions to influences by social, institutional or ecological forces. Hornborg (2019) comes closest to an alternative theory of value, suggesting that exchange value correlates with increasing entropy and declining exergy. Yet he also insists that monetary and energetic metrics are incommensurable, rejecting any reduction of economic value to embodied energy or exergy. Instead, he links money values to socially constructed relations of power (Hornborg, 2019, 2024). While prices are undoubtedly shaped by monopoly, bargaining, purchasing, and political power, this leaves underexplored the question of how such powers systematically determine value and prices. Odum's (1988) emergy theory was perhaps the boldest attempt to ground value physically, but it was ultimately normative rather than explanatory: he did not claim that actual market prices reflect emergy content, only that ecologically rational prices ought to be proportional to it (see Schlaudt, 2025).

An important question here is whether a theory of value is necessary, and this cannot be answered in the abstract, but only in relation to the purposes at stake. In this paper we have sketched a theory of the economic process based on the notion of surplus, without needing the lexicon of value. There is, however, a pending question concerning the substance of surplus: if it is energy, one might claim we are approaching an energy theory of value, and if it is labor time, we are close to a labour theory of value, even if we are not using these terms. The question of value was indeed lurking at the background of the debates between Serhiy Podolinsky and Marx and Engels; debates resuscitated more recently by ecological and Marxist economists.

Appendix B. Revisiting the Podolinsky debate

Ecological economists and Marxists have diverging views on the roles of energy versus labour in the economic process. We can approach such differences in the terms of the debate over the reception of the work of 19th century Ukrainian socialist, Serhiy Podolinsky by Marx and Engels (Foster and Burkett, 2004; Martinez-Alier et al., 2026).

Podolinsky linked surplus value to the net solar energy workers appropriated with their labour from nature offering an early ecological-economic contribution to the use of energy metrics in economic analysis (Martinez Alier, 1991). More controversially, however, Podolinsky's contribution could be read as suggesting that energy is a better metric of (exchange and surplus) value than labor time.

Podolinsky's account, combining Marx's work with energetics, is similar to our model here, as he showed *how solar energy is captured and transformed by laborers and appropriated by capitalists*. This is not a "physiocratic" account, whereby surplus resides in nature, but in accordance with Marxist and ecological economic theories of metabolism; one that recognizes that it is only through human labour that solar surplus is captured and put to use. Fig. 3 offers a simple illustration of this, showing how:

- i) surpluses originate from the positive net energy captured from nature (via farming, in this visual, but more generally via husbandry, energy extraction, etc.) (Panel I);
- ii) productivity-enhancing innovations of the means of production increase the captured surplus (Panel III);
- iii) capitalists can appropriate surpluses during extraction (Panel II) or during industrial processing (Panel IV), and they can increase their share by increasing the working time of workers or by reducing worker's reproduction costs and their 'depense' by encroaching on workers' free time.

There is a difference here between primary, extractive activity where the original, physical surplus is drawn out of nature (Panels I-III), and secondary or tertiary industrial or service activity (Panel IV), where physical surplus is only spent, and redistributed in favour of industrial capitalists,

but not ‘produced’ (see also [Taşdemir Yaşın, 2017](#)). Physical surplus, that is, is spent turning raw into processed goods, capitalists keeping for themselves an extra share along the way. Left out of [Fig. 3](#) and Podolinsky, but a crucial consideration is the labour/energy spent to produce workers themselves (care work etc.), the labor/energy spent to produce the goods the workers consume for their reproduction, and the ‘dead’ labor/energy spent to produce the means of production.

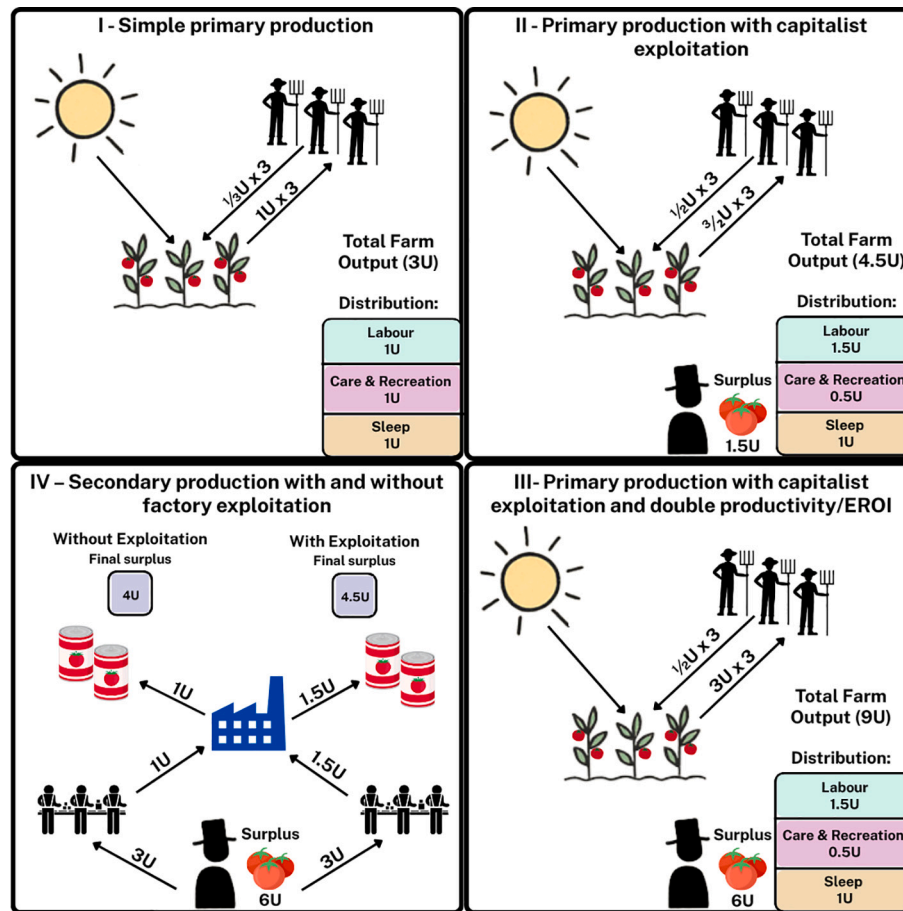


Fig. 3. A simple illustration of surplus creation and distribution in an agri-business.

Label: Assume there are three identical workers, each spending 1 U of endosomatic energy per full day. In each panel we show (a) how those 3 U of input-energy get allocated, (b) the total output (in U), and (c) how much of that output is returned to workers vs. kept as surplus by a capitalist. By surplus, we mean anything produced beyond the labourers' own subsistence (reproduction). Under capitalism, that extra goes to the capitalist. Each worker works a full day where she spends 1 U of endosomatic energy – distributed (as an approximation) equally between 1/3 (8 h) working (“labour”), 1/3 caring and resting, and 1/3 sleeping. In simple production with no surplus (Panel I), each worker works 1/3 of their day and produces tomatoes with enough calories from the sun to sustain her for the full day (EROI of 3:1). The physical surplus (net energy) is 2 U and goes to the workers for care, recreation and sleep. In Panel II, extra surplus is produced (net energy increases from 2 to 3.5 U) and appropriated by a capitalist who forces workers to work for 4 h more - from 1/3 of the day to 1/2. EROI remains 3, so each worker now produces 3/2 U of tomatoes. Total product is 4.5 U; the capitalist returns to workers 3 U to pay for their reproduction and keeps 1.5 U of surplus (which, correctly, is three times the 0.5 U of additional endosomatic energy spent by the workers due to exploitation, i.e., an EROI of 3). In Panel III, due to a technological innovation, EROI doubles to 6, so that now each exploited worker works half of the day spending $\frac{1}{2}U$ and gets back from production $\frac{6}{2} = 3U$ of tomatoes, increasing total farm output to 9, and capitalist's surplus from 1.5 to 6 U. In Panel IV we assume an integrated agribusiness where the capitalist produces canned tomatoes, processing raw tomatoes into the factory. Consider panel IV as an extension of Panel III, where the capitalist takes the 6 U of surplus as farm produce and uses 3 U out of it to pay for the reproduction cost of tree factory workers. If the factory workers are not exploited, they produce 1 U ($3 \times \frac{1}{3}U$ each); if they are exploited, they produce 1.5 U. So the final surplus for the agribusiness capitalist who oversees both the farming and the processing of tomatoes is either 4 U, without exploitation ($6 - 3 + 1$) or 4.5, with exploitation ($6 - 3 + 1.5$).

One Marxian critique of Podolinsky, expressed early by Engels, is that the energy quantities at stake cannot be calculated ([Foster and Burkett, 2004, 2008](#)). True as this may be, neither can the labor time embedded in goods or means of production be calculated, without this disproving or rendering Marx's theory irrelevant. It is equally difficult to calculate the energy or embodied energy of a ton of fertilizers as it is to calculate its dead and living socially average labor time. This cannot be an argument against Podolinsky, as it is not a valid argument against Marx ([Kallis, 2018](#)).

The second objection concerns qualitative differences between different labouring or energy processes, which cannot get reduced to a calorific denominator ([Foster and Burkett, 2004, 2008](#)). This is also correct, and very much accepted by ecological economists who reject energetic theories of value and see energy as one, among many, useful economic metrics ([Hornborg, 2022; Martinez-Alier, 2002](#)). Likewise, however, reducing value to labor time, as Marxists do, can be equally reductionistic and yet theoretically useful. The question is not the reduction per se, but the use it is put towards.

A core Marxian argument here (see Appendix I) is that the reduction of value to labor time is not a theoretical or ethical choice, but an empirical fact of how market exchange under capitalist relations reduces the value of goods in exchange into their socially average labor time ([Foster and Burkett, 2004; Kay, 1979](#)). The problem, however, is that this empirical claim, as any claim about the determinants of economic value, is

unverifiable, since embedded labor times (like ‘utility’) cannot be really measured. The merit of the Marxian proposition then should be judged in terms of its explanatory power (Harvey, 2018; Kallis and Swyngedouw, 2018), which, as far as explaining exploitation, or capitalist crises, is strong. Likewise, however, one could hypothesise, that market exchange reduces the exchange value of goods to their embedded energy or exergy, abstract and socially average too, and see where this gets them.¹¹

Indeed, the differences between energy and labor, or Podolinsky and Marx, might be exaggerated (see Foster and Burkett, 2008). Ecological economic and Marxian versions of social metabolism converge if we understand labour as an expenditure of energy, not only endosomatic, but including also the exosomatic energy spent to produce that labour. Marx, in fact, acknowledged that workers do not magically embed commodities with more labor than the labor needed for their reproduction since “in no case would ... surplus product arise from some innate, occult quality of human labour” (Marx cited in Foster and Burkett, 2008, 144). The extra energy with which laborers endow goods can only be an energy outside the laborers’ bodies. Foster and Burkett (2008) re-present Marx’s theory in energetic terms: surplus value being the excess of “the amount of productively expendable energy encapsulated in labour-power ... from the caloric quantity of useful work needed to produce the worker’s commodified means of subsistence” (p.147). Of course, they cannot mean here the endosomatic energy workers expend, but the energy – endosomatic and exosomatic – workers mobilize and convert; what we called physical surplus. Laborers, in other words, capture an immense net energy (physical) surplus, higher than the sum of the energy they spend to extract and process it, and to the extent that there is growth, a quantity of energy higher than the energy that goes into reproducing the goods they need for their subsistence and enjoyment.

We are speculating here, but one untold concern by Engels and other Marxists with Podolinsky’s account may have been that the importance of wage workers’ exploitation may be diluted in the sea of energy surplus extracted out of nature. This would be wrong though. First, because if we focus not on the endosomatic calorific needs or expenditures of workers but on the endo and exosomatic energy necessary for their reproduction, their energy cost is likely to be substantial.¹² In so far as human labor is non-substitutable by machines for certain processes, there remains a strong incentive for capitalists to exploit workers and reduce the energy cost of their reproduction as much as possible.

Second, as Fig. 3 indicates, adopting a Podolinskian/extended understanding of the economic process does not let capitalists off the hook; on the contrary it reveals how they unfairly appropriate the gifts of the sun, which belong to humanity as a whole, and that they do so by exploiting the fruits of labor on the one hand and owning the ‘gifts’ of technology on the other, which in principle should be common property (who invented the wheel after all?).

One Marxian reaction to our argument could be that exploitation is a social relation under capitalism and not a biophysically determined feature. But we did not claim here that there is anything natural about surplus making – on the contrary, and as Fig. 3 illustrates, the extraction and distribution of physical surplus in the economic process is indeed the result of social relations. And indeed what is unique under capitalism is the redistribution of surplus principally through the wage-labor relation, something that has not been the case in other social formations.

Another reaction could be that our model is flirting with energy reductionism (see for example the critique by Hornborg, 2019). Our intention here, however, is not to claim that the economic process should be reduced to, and represented by, single energy-calorific metrics. As we noted in Section 2, there are important qualitative aspects too in the economic process, and differences between different forms of energy and labouring. Beyond energy, ‘matter matters’ too, and different material arrangements also have different implications in terms of entropy and pollution. As any scientific reduction, the value of our model should be judged by what it helps grasp. Compared to Marxist models based on a labor theory of value, the model proposed here could explain, for example, why high EROI fossil fuels were so important for capitalist/economic growth. It could also explain why the ruling capitalist class in the imperial core could afford to reduce domestic exploitation in the 20th century, benefiting from fossil fuel or unequal exchange surpluses. It could allow engaging with the question of why climate-related energy constraints threaten to reduce growth, unless improvements in EROI or exergy efficiency overcompensate. Or consider how robotization, automation or artificial intelligence, energy-intensive as they are, may nevertheless increase energy surpluses by reducing the energy required per unit of work (for instance, if the energy needed to power machines is lower than the energy required to reproduce human labour performing the same tasks), unless the additional energy demand pushes the system towards lower-EROI energy sources. Treating energy as ‘use value’ (Foster and Burkett, 2008) or treating energy sources like coal, the same way as other passive materials metabolized by human labor (Kay, 1979), cannot do justice to the special importance of energy in the economic process (to put it simply, coal does physical work, stones do not).

New Marxian frameworks address to some extent the above concerns. Harvey’s (2020) elaborated scheme of Marx’s theory of capital circulation, for example, brings together all different forms of surplus making: at its centre is capital accumulation with wage labor exploitation, an accumulation renewed with free-for-capital gifts of nature and human nature. Free or cheap carework reduces the cost of wage labor, whereas free (cheap) energy increases the productivity of the means of production (see also Moore, 2015); the effect of both being higher surplus value. Harvey’s model represents capital accumulation and is framed from the point of view of capital, starting with the money a capitalist puts in to buy the means of production and workers. The picture we offered here applies instead to all human economies and can be used to compare capitalist and non-capitalist orders. In our framework ‘nature’ is not an exogenous free gift, which is how it is treated by capital, but a surplus that humans appropriate by spending work and energy. The energetics details of our model make it more suitable for analyses that deal with resource constraints, whereas the anthropological and dense components unpack the social processes that mystify, orchestrate and give meaning to the established circulation of surplus.

¹¹ A different version of the Marxian argument would be that labor time is what value becomes under the distorted perspective of capital – and that it is capitalists who care about labor time, not the theorists. In practice of course, the capitalists care about profits, which are determined by many more things than labor time. And even though capitalists care about labor time (trying to extend the working day, for example), they also care about the intensity of work, that is the human energy extracted out of a given contracted time. Hence the monitoring of the factory floor, or the relative lenience towards remote work or reduced working hours as long as ‘productivity’ increases.

¹² Sam Altman, CEO of Open-AI, seemed aware of this when defending the high energy consumption of Artificial Intelligence against critics, pointing to the even higher energy requirements of producing the intelligent humans that AI promises to substitute (Berger, 2026).

Data availability

No data was used for the research described in the article.

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