On the notion of value. A comparative analysis between economic and biophysical approaches

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Abstract. The plurality of dimensions and topics covered by the SDGs reflects the need to assess the value of organizations, cities, and societies using a holistic approach that considers different dimensions and criteria. It is much needed to shift towards inter-disciplinary, multi-criteria and integrated perspectives, opening the door to views able to consider different scientific points of view when assessing the most "valuable" pillars in human societies. This need highlights a controversial question: "what do we mean when we refer to a concept so broad such as the one of "value" and its measurement"? The concept of value and welfare have changed throughout the years, also in relation to the historical context and societal structure and needs of the time. But time has not been the only factor in differentiating value theories. While most organically structured definitions of value have originated, as expected, from the developments of the economic discipline, this issue has also been addressed by scientists belonging to the biophysical realm. In this paper, a comparative overview of the main economic and biophysical value theories, developing from very different epistemological backgrounds, is provided. Results suggest the need to foster inter-disciplinary communication on the notion of value, which is an abstract construct at the root of our societies and economies.

Keywords: Theory of value; Valuation; Biophysical accounting.

1. Introduction

1.1 An important long-standing debate for our societies is nearing a turn?

The problem of value has always played a role of great importance in the history of economic thought, being at the very core of any societal system and economic paradigm. The famous economist Schumpeter claimed that "*The problem of value must always hold the pivotal position, as the chief tool of analysis in any pure theory that works with a rational schema*" (Schumpeter, 1954). Therefore, our current demand for more just and sustainable societies requires to be accompanied by the definition of alternative, more complex and viable conceptions of value or "what is valuable", through the problematization of current mainstream evaluation approaches. The latter are often rooted in neo-classical reductionist assumptions which reflect a too simplistic vision of human beings, the environment, and societies. This is usually exemplified by a mono-disciplinary vision of value expressed through a single monetary metric. Even in the sub-discipline of environmental economics, economists' approach seems to reject different scientific perspectives, not truly taking into consideration non-economic metrics, complex systems' theory nor the notion of multi-dimensionality in value (Turner et al., 2003).

Even though it may seem an old-fashioned debate, outmoded or purely theoretical, reasoning around the concept of value is necessary to understand the bedrock of our societies and where they are headed. In the words of the ecological economist Elke Pirgmaier: "*understanding and exploring what value is, how it gets reproduced, and how use value and exchange value considerations are entangled serves as a powerful starting point to understanding the system as a whole*" (Pirgmaier, 2021). The relevance of the issue is demonstrated by the recent debate raised by Pirgmaier's 2021 article "The value of value theory for ecological economics", where the author argued that the inter-disciplinary field of ecological economics should recover interest in classical labour theories of value (LTV), especially marxian (Pirgmaier, 2021). The paper received almost immediate and direct response by the eminent Danish ecological economist Inge Røpke and, one year later, also by the famous Swedish antropologist-ecologist Alf Hornborg, both in strong disagreement with Pirgmaier's suggestion (Hornborg, 2022; Røpke, 2021). The authors' responses to Pirgmaier's apology of marxian "embodied labour" value theory are dismissive regarding any presumption of finding in "objective value" theories any silver bullet answer. For them, there will never be such thing as an underlying substance able to disclose the true value of something, whatever underlying variable may be considered: energy, labour, information, entropy, etc. The fact that goods and services are bought and sold in markets at relative prices is empirical evidence, but there is no evidence that the formation of these prices depends on some underlying metric. This is because the realms of natural sciences and economics cannot be confused. Economic value, argues Hornborg, is merely a concept, a human artefact like money that emerged at a certain point in history inherently to the economic domain, and will be always dependent on contextual/cultural evaluation. For these reasons it is pointless to try to understand it in terms of other metrics, because "*the only conceivable metric for measuring it is money*" (Hornborg, 2016, 2019).

But at the same time, the authors highlight important functions for heterodox perspectives on value which is to integrate non-economic values and to account for non-exchanged metrics into valuation. Even if they do not have explanatory power, this does not mean that biophysical metrics should not be used in valuation: "*while the monetary exchanges obscure the asymmetries of the transfers of resources, the various biophysical metrics provide very important analytical tools to disclose what is going on*" (Røpke, 2021). Underlying biophysical quantities therefore refer to different domains, but they should be integrated to redesign processes of evaluation and accounting (Hornborg, 1998), shifting the focus from the elusive concept of value to the concrete act of valuation. In this way the two authors try to draw a line on the old theoretical debate on value, through an innovative and pragmatic approach.

1.2 Why this paper?

To integrate non-economic visions of value into valuation it is necessary, first, to know and understand economic value theories and, then, to put them in comparison with other approaches. From these needs the idea of this article came out. The selected choice of disciplines, theories, and inter-disciplinary approaches dealing with the concept of value is broad but has no ambition to be considered exhaustive. The aim is to highlight the most important concepts and definitions, selected according to authors' mixed backgrounds (economics and ecology) in both the economic and biophysical fields. The main goal of the paper is to present a comprehensive overview to foster communication and inter-disciplinary collaboration among these different academic arenas. Economic and non-economic (such as biophysical) ideas of value should be regarded as complementary rather than mutually exclusive (Melgar-Melgar & Hall, 2020).

2. The concept of value in the history of economic thought

First thing to clear is what is the objective of a theory of value. In the economic categorization, the value problem has always taken a twofold dimension: "value in use" or "use value" vs "value in exchange" or "exchange value". Use value refers to the appropriation of the material aspects of goods and services and usually it is describable in qualitative terms because connected to the capacity to satisfy concrete, real human needs in a specific environment (Pirgmaier, 2021). Exchange value, on the contrary, it's the value that a commodity expresses in an exchange, represents a "*ratio between any two commodities or services*" (Schumpeter, 1954) and, therefore, it is describable in quantitative terms. The objective of economic value theories has always been to investigate what determines the exchange value and why the exchanges take place at the relative prices observable in the real world (Schumpeter, 1954). Gómez-Baggethun et al. (2010) identify two major breakthroughs in value theories' development that mark the transition from one view to another: the "*Post-Physiocratic Epistemological Break*" and the "*Marginalist Revolution*". Following this view, we can identify roughly three schools of economic thought which gave radically different answers to the value question: pre-classical, classical and neo-classical school. It is possible to characterize them as follows:

- Pre-classics: gave great importance to Nature and in particular land as sources of wealth.
- Classics: put very much emphasis on human labour factor of production as a driver of value.
- Neo-classics and later developments: marked the start for a continual increasing importance of the capital factor of production over the others, and through the concepts of "marginal utility"

and “relative scarcity” marked the definitive decoupling of economic processes from biophysical variables.

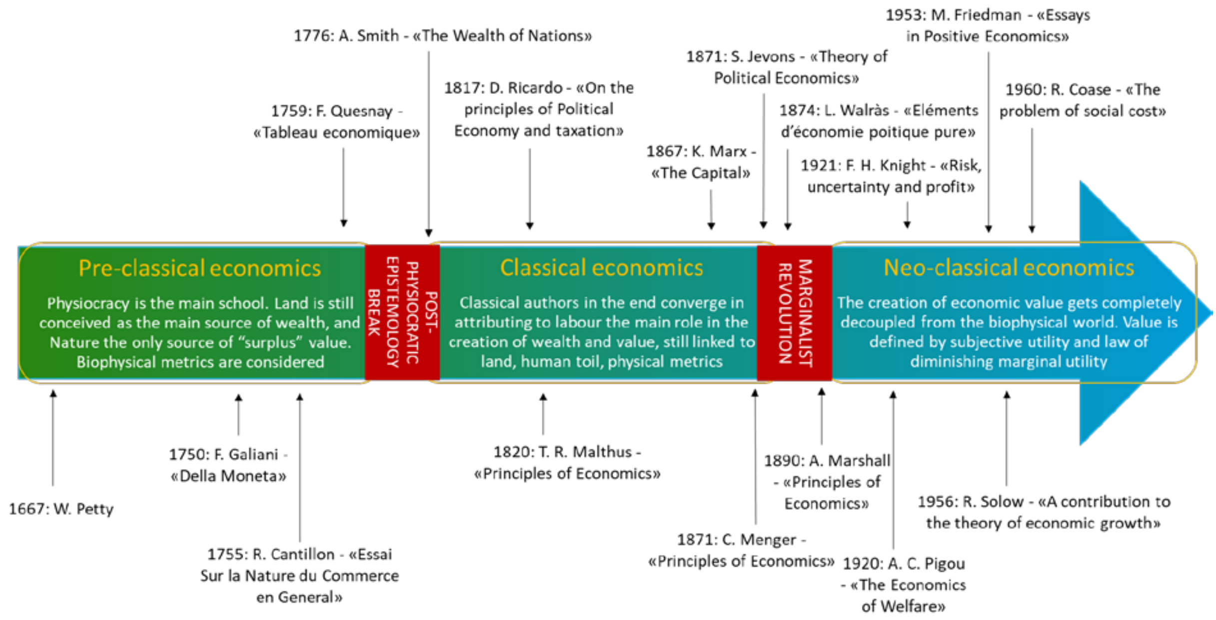

Figure 1. Timeline of the history of economic thought.

Figure 1 represents a timeline of the development of the concept of value in economic thought, by considering milestone works of some of the most important authors. As shown in the figure, economic value theories’ evolution encompasses a shift from pre-classical notions of value of the physiocrats centred on Nature laws and agricultural productivity (Cleveland, 1999; Halkos, 2011; Quesnay, 1759) to modern neo-classical economics, where utility and marginal utility are the ultimate standards of value (Jevons, 1871; Marshall, 1890; Menger, 1871; Persons, 1913; Walras, 1874). After marginalist revolution, the construct of “homo oeconomicus” will become mainstream, in the attempt to provide economic analysis with the same level of abstraction and predictability of mathematical sciences. The “homo oeconomicus” is a key concept because it can be considered the smallest standardized unit of analysis in economics, equivalent to the atom in Newton’s physics, and the centre of application of evaluation. The construct has been created through gradual stratifications of assumptions, from classical roots (Mill, 1836; Smith, 1776) to the utilitarian characterization and insatiability of human wants and needs (Bentham, 1789; Jevons, 1871; Marshall, 1890) to the final neo-classical hypotheses of perfect rationality and foresight, via the elimination of uncertainty (substituted by risk) with F. Knight, and the theorization of the “as if” assumption by M. Friedman (see, among others, Raworth, 2017; Pigou, 1920; Friedman, 1953; Knight, 1921; Marshall, 1890; Pareto, 1906). Between pre-classics and neo-classics, for about one century (1770s-1870s) the field has been dominated by the classical literature among which the most relevant authors are Smith, Ricardo, and Marx. Although with differentiated approaches, they all adopted “cost of production” theories of value, recognizing the importance of all factors of production, but putting the greatest importance on "embodied labour" for the explanation of exchange value (Marx, 1951, 1990; Meek, 1973; Smith, 1776; Stigler, 1958). This is the reason why in contemporary literature we can see classical value theories synthetically referred as "labour theories of value", sometimes abbreviated with the acronym "LTV" (Hornborg, 2022; Rodríguez & Cáceres-Hernández, 2018; Røpke, 2021).

Among other historically influential authors, we can mention Galiani and Malthus. The first was a peculiar author who, although being a pre-classic, can be considered an early precursor of neo-classical theories of value based on rarity, subjective utility and opportunity cost (Giocoli, 1999). Moreover, in its main treaty (Galiani, 1750) he also exposes a theory of markets equilibrium with the obtainment of collective welfare via individualistic and egoistic behaviour by economic agents which closely resembles the "invisible hand" metaphor by Adam Smith. The second (the famous Thomas Malthus), played a key role in the development of environmental thinking in economics. He seems to adopt a labour theory value, of the "commanded labour" kind, similarly to Adam Smith; moreover, through his model he predicted that wages over the long run would tend to the subsistence level (Malthus, 1820).

A first trend observable in figure 1 shows a historical transition from value theories rooted in "real" biophysical dimensions to gradually more "abstract" formulations (Gramm, 1988). The physiocratic age (at the left or beginning of the arrow) put in fact the most emphasis on real, natural metrics. Agriculture fuelled by sun's energy was deemed the sole true productive activity able to create net value or "*produit net*", while the other sectors where only responsible for value "circulation" (Dale, 2020; Quesnay, 1759). The pre-classics "*belief that Nature was the source of wealth became a recurring theme throughout biophysical economics*" (Cleveland, 1999) and will be at the core of many modern biophysical approaches to economics, such as ecological economics. In classical authors (centre of the arrow), the emphasis is still on real metrics and use values, but with increasing levels of abstraction. If in the physiocrats value emerges as "a pure gift" of nature, but its production depends on human labour and ingenuity, in the classics the relation of importance is inverted. Land is still important, especially in Ricardo, but (also reflecting the changes in economies structure during the industrial revolution), human labour time or "embodied labour" is the key metric of value. From Smith's "commanded labour" and "toil and trouble" to Ricardo's "comparative quantity of labour" or Marx's notion of "socially necessary labour time", classical emphasis is always on labour, and with increasing levels of abstraction (Burkett, 2003; Marx, 1951; Meek, 1973; Pirgmaier, 2021; Smith, 1776; Stigler, 1958; King & McLure, 2014).

Finally, at the right or the end of the arrow, neo-classical authors on value theory were inspired by the ambition to give economics the mathematical formalism of mechanical physics (Drakopoulos & Katselidis, 2013). This resulted in the almost complete conceptual decoupling of economics and economic value from biophysical metrics and the real world, with exchange values becoming the sole value dimension. The marginalist revolution happened for various reasons ranging from enthusiasm towards scientific progress, structural changes in modern industrial economies characterized by the increase in concentration of capital, to more ideological reasons (Gómez-Baggethun et al., 2010; Gramm, 1988; Schumpeter, 1954). Otte B.A. Hons identifies three key elements in the marginalist revolution that brought to our current neo-classical mainstream: "*The first was the subjective interpretation of value, and an increased analytical focus on demand as the engine of economic activity; the second was the postulate of scarcity as the cause of economic value; and the third was the methodological transition from literary philosophy to mathematical analysis*" (Otte B.A. Hons, 2014). Marginal utility and relative scarcity became the ultimate sources of value, which became an entirely contextual and subjective construct, detached from objective physical content, value in use or any other objective consideration (King & McLure, 2014). A second trend is in fact identifiable (Figure 2) in the development of economic value theories: the evolution from "objective" interpretations of value focused on production (supply-side) to "subjective" ones focused on the moment of the exchange (demand-side). The first are rooted in the physical quantification of production inputs and is independent from history (a-historical), culture and contextual judgment. The latter, on the contrary, assume that the value of anything can constantly change, depending on the "subjective" interpretation of individuals, given their preferences' structure in the specific moment. Markets exist and operate, according to neo-classics, because things provide different levels of utility to different individuals and businesses in different contexts and times, and not because (as classics argue) the value of things in the market departs from their "real", "objective" value, defined as "*the cost of their attainment*" (Gramm, 1988; von Böhm-Bawerk, 1894). This approach allowed Jevons to argue against classical "embodied labour" theories that it is the value of labour which "*must be determined by the value of the produce, not the value of the produce by that of labour*" (Jevons, 1871). With the establishment of a direct relationship between marginal utility and exchange values of commodities, the same Jevons claimed to have solved the long standing "paradox of value" first formally exposed by Adam Smith, also known as the "water-diamond paradox" (Douai, 2009; Otte B.A. Hons, 2014): *"Nothing is more useful than water: but it will purchase scarce any thing; scarce any thing can be had in exchange for it. A diamond, on the contrary, has scarce any value in use; but a very great quantity of other goods may frequently be had in exchange for it"* (Smith, 1776).

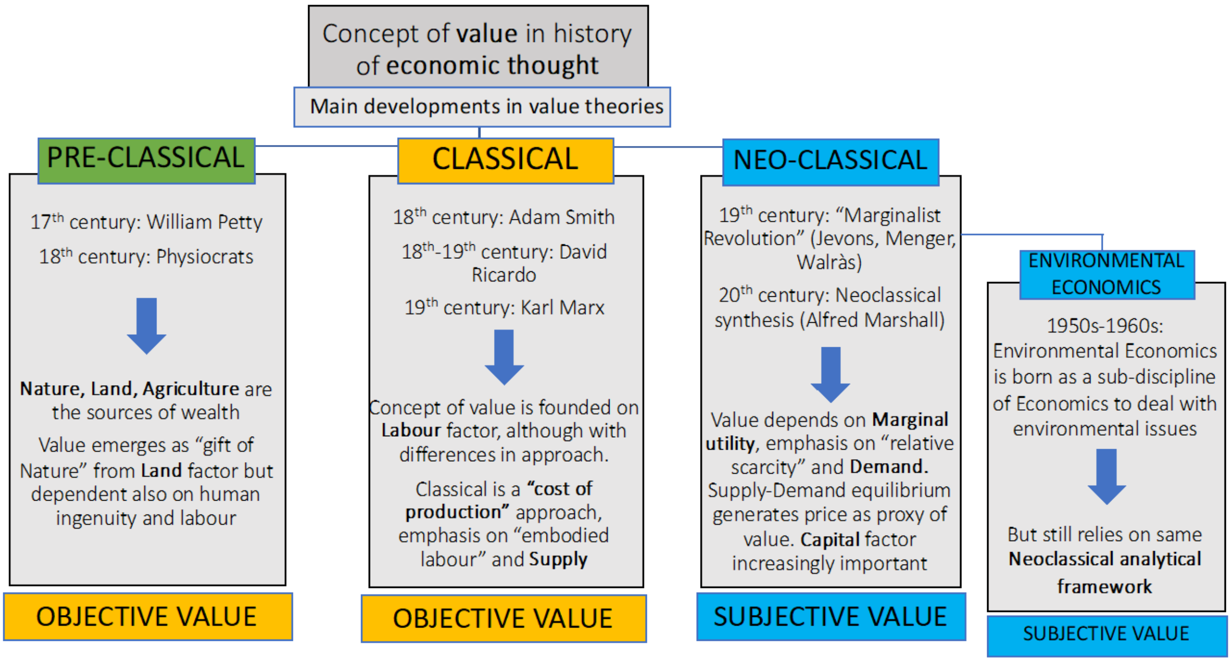

Figure 2. Classification of value theories in history of economic thought.

2.1 Environmental Economics

Although posing themselves as alternative to traditional economists on many aspects, environmental economists' reference value theory is the same. Adopting a subjective value framework, through the use of contingent valuation (WTP or WTA), environmental economists assess in fact the value of biophysical resources proportionally to their perceived relative scarcity and marginal utility. This approach is what caused environmental economics to be accused of wanting to "*put a price tag on nature*" (Beder, 1996, 2011; Wierenga, 2003). According to environmental economists, the cause of environmental problems can be essentially reduced to the inability of markets to properly "price" the environment (Beder, 1996, 2011), which results in an inadequate recognition of its value for the society. The solution, according to environmental economists, is not to find complementary measures of value or innovative evaluation methods, but to remedy to markets' incompleteness and "internalize the externality" (Pearce, 2002).

The Total Economic Value (TEV) framework can be considered the reference model for a taxonomy of values in modern economics, including environmental economics. The model has been designed in such a way to be complete, considering and reducing all the different aspects of an asset through the mono-criterion lens of economic value, without incurring in double counting (Chee, 2004; National Research Council, 2005). There is growing consensus that TEV is the most appropriate framework to orient policy makers in decision making (Kumar & Kumar, 2008).

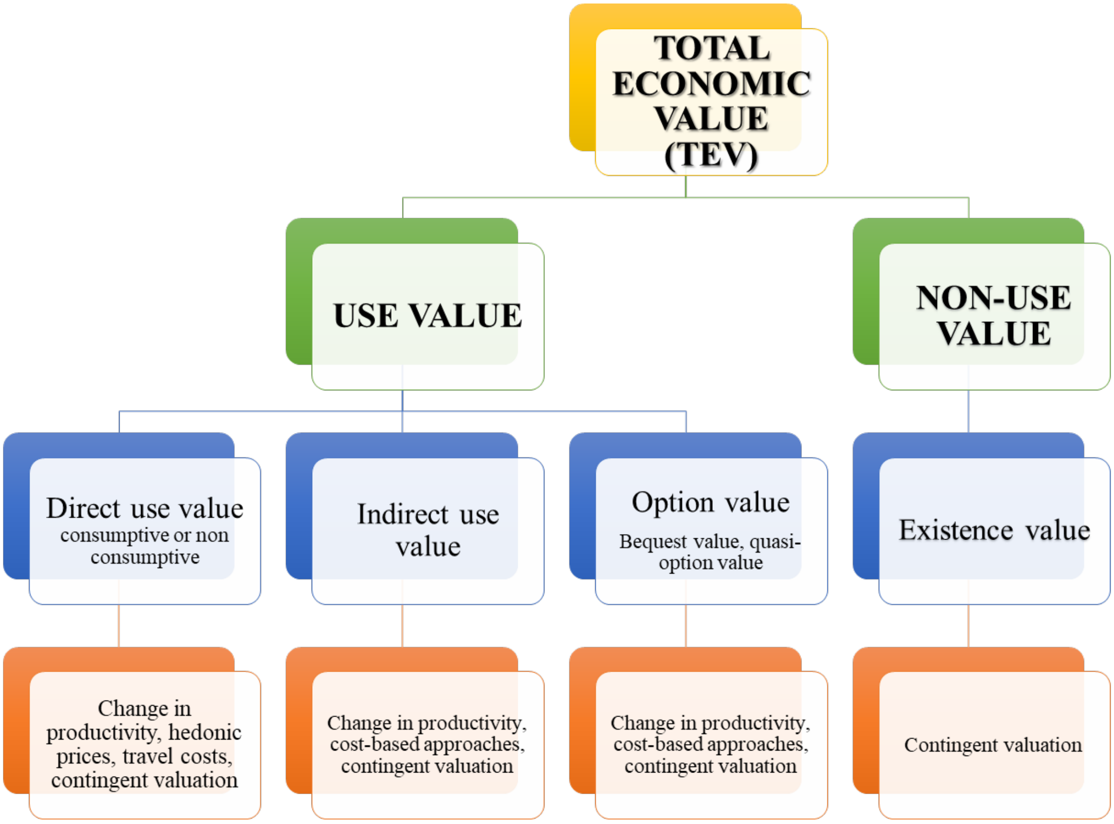

Figure 3. The Total Economic Value (TEV) framework (modified from Alcamo et al., 2003).

As an output of the first section of literature review, and to recap the concepts expressed so far, we propose the classification of the main economic theories of value included in Table 1.

Table 1. Classification of most important economic value theories in history of economic thought.

School of thought	Authors	Approach to value	Nature of value	Historical context
Pre-classical	Sir William Petty	First author to mention labour together with Nature	Objective	17th century
Pre-classical	Physiocrats	Nature, land, agriculture	Objective	18th century
Pre-classical	Ferdinando Galiani	Precursor of neo-classical theories, subjective utility	Subjective	18th century
Classical	Adam Smith	Cost of production, commanded labour, toil and trouble	Objective	End of 18th century
Classical	David Ricardo	Embodied labour, absolute scarcity, land as a constraint	Objective	18th-19th century

Classical	Thomas Malthus	Commanded labour, labour wages tend to subsistence level	Objective	Early 19th century
Classical	Karl Marx	Abstract Socially Necessary Labour Time (ASNLT), surplus value from labour exploitation	Objective	19th century
Neo-classical	"Marginalists": Jevons, Menger, Walràs, Marshall et al.	Marginal utility, relative scarcity, Supply-Demand static equilibrium	Subjective	19th-20th century
Environmental Economics	Various authors	Neo-classical. Total Economic Value Framework	Subjective	From 1950s

3. Biophysical approaches to value

The current section is dedicated to describing how aforementioned theoretical assumptions at the basis of neo-classical value framework have been challenged by heterodox economic perspectives and non-economic approaches coming from other scientific disciplines and inter-disciplinary fields. The latter can be defined "biophysical" since they are rooted in natural sciences such as biology and physics. These approaches, given their very different epistemological background, result in very different conceptions of the abstract construct which is value. As shown in Figure 4, we can think about these alternative approaches as being all linked together in the history of the critique towards neo-classical economic theory, in a process of mutual contamination and continuous evolution, with many authors contributing to more than one perspective (for example, J. Schumpeter and N. Georgescu Roegen). We will not cover "philosophy" and "ethics" contributions, but we inserted them in the diagram to highlight the fact that many developments undertaken in the other fields are born out of different philosophical traditions or ethical conceptions. We can mention for example the conflicts between utilitarian consequentialism and deontological ethics, or between anthropocentric value and intrinsic value or biocentrism (Davidson, 2013).

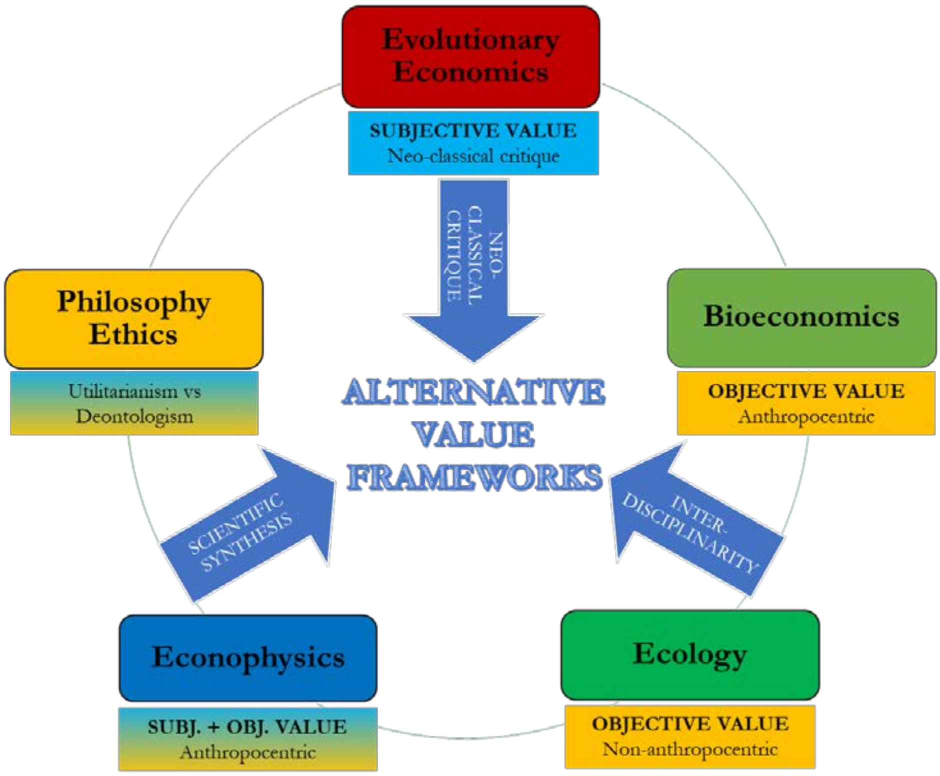

Figure 4. Classification of the main non-economic approaches to value theory emerged in the literature review process.

3.1 Evolutionary Economics

Evolutionary ideas put the focus on the analogies between economics and evolutionary biology and can be traced back to teachings of the famous economist Joseph Schumpeter and the Bioeconomics founder Nicholas Georgescu Roegen (Heinzel, 2013). Schumpeter put much emphasis on "*qualitative change*", innovation dynamics and entrepreneurship as fundamental drivers of value and development of the capitalist economy (Schumpeter, 1934, 1954). Georgescu-Roegen stressed the fact that neo-classical mathematical formalism was a tautological system, not capable of "*capturing the evolutionary qualitative changes that characterize socio-economic development*" (Melgar-Melgar & Hall, 2020). A major inspirator of both the institutionalist and the evolutionary school, Thorstein Veblen, seems unclear given that in "The Theory of the Leisure Class" (Veblen, 1899) opts for a subjective concept of value, while in "The Engineers and the Price System" (Veblen, 1921) proposes an objective system to determine value in the form of a sort of scientific collectivism delegated to technicians. But what is important in his theory of "*conspicuous consumption*" (Veblen, 1899) is the underlying critique to the atomistic conception of the rational economic man. Far from being a "*self-contained globule of desire*", human beings are more like animals which live in herds: the social influence and inter-dependence is paramount in decision making, to the point that people can consume with the sole motivation of signalling others their social status, or in the hope of "*keeping up with the Joneses*" (Raworth, 2017).

T. Veblen deeply believed in the necessity of a methodological change in the economic discipline, claiming that *"modern sciences are evolutionary sciences"* (Veblen, 1898). A way to turn economics into an evolutionary science is to introduce aspects of Darwin's explanatory model of biological evolution to economic theory, giving birth to modern evolutionary economics (Cordes, 2007). In this sense, the evolutionary approach is an approach that is interested in the dynamic aspects of value, trying to explain "why that something is what it is at a moment in time in terms of how it got there" (Dosi & Nelson, 1994).

Theoretical milestones of this line of thought can be considered "Uncertainty, evolution and economic theory" (Alchian, 1950) and "Substantive and procedural uncertainty" (Dosi & Egidi, 1991) where key points of evolutionary critique towards neo-classical "homo oeconomicus" are deployed. Alchian highlights the need to incorporate in economic analysis incomplete information and uncertainty as axioms and not incidents in individuals' decision-making processes. The neo-classical view of human beings as perfectly rational, profit maximizing units of selection, is in fact deemed by the author as unrealistic because decision making in the real world is characterized by unavoidable uncertainty. Uncertainty in fact arises from at least two sources: imperfect information and foresight, and human incompetence in solving some complex issues. In such a context, uncertainty in individuals' expectations should be regarded as pervasive, not the exception, and "*where foresight is uncertain, profit maximization is meaningless as a guide to specifiable action*" (Alchian, 1950). According to Alchian, then actions should be considered guided by adaptive, imitative, and trial and error behaviours in the pursuit of "positive profits" or "success" (assimilable to survival in this context) rather than "maximization" of a single criteria or variable. Such an approach *"embodies the principles of biological evolution and natural selection by interpreting the economic system as an adoptive mechanism which chooses among exploratory actions"* (Alchian, 1950). This closely resembles the way in which adaptive mutations of genes are chosen in biological evolution via natural selection (Dosi & Nelson, 1994).

Dosi and Egidi critique draws from Simon's distinction between "substantive" and "procedural" rationality (Simon, 1964) introducing the notions of "substantive" and "procedural" uncertainty to discuss the two possible origins of uncertainty and move their critique to rational economic man (Dosi & Egidi, 1991). Uncertainty may have two origins, *"1) the lack of all the information which would be necessary to make decisions with certain outcomes, and 2) limitations on the computational and cognitive capabilities of the agents to pursue unambiguously their objectives, given the available information"* (Dosi & Egidi, 1991). The authors argue that the neo-classical rational theory of choice under uncertainty explicitly ignores the second source of uncertainty. In complex problem-solving tasks in non-stationary environments, economic behaviour is characterized by strong procedural uncertainty; in such an environment, "as…if" assumptions mentioned by Friedman (Friedman, 1953) do not hold. Therefore, *"we shall analyse the relationship between decisions and problem-solving in environmental conditions where "uncertainty" stems indeed from the limitations intrinsic to the computational and* *recursive features of a "rational" decision process*" (Dosi & Egidi, 1991). Authors show that in such contexts the economic agents will model their behaviour in form of intelligent routines, functional in their limited environment, which are the unit of analysis of evolutionary economists.

Evolutionary economists believe in value pluralism: the choice of methods shall derive from close observation of the subject matter under scrutiny (Heinzel, 2013). This can be considered the opposite of rational choice theory (RCT) which is an optimizing, domain-general, sensitive to dominance and risk neutral method of choice, which is considered universally valid and applicable to any situation by mainstream economics. Evolutionary analysis assumes complex, optimizing mechanisms to be too costly (in terms of energy, time and resources spent) to be applied in real, day by day evaluations by human agents and relies on simple heuristics:*"decision making based on simple heuristics is a natural consequence of the fact that humans are biological organisms and thus subject to the way biological evolution works"* (Schulz, 2013). Building blocks of evolutionary theories, which depart very much from neo-classical assumptions, are therefore:

- Simple heuristics decision making: satisficing decision making based on simple heuristics is deemed more realistic than optimizing, domain general choice theory
- The units of selection are different: not only individuals but also firms, practical routines, organizations, are considered as units of choice, or agents in society
- Integration of the notions of imperfect foresight, rationality and uncertainty in economic behaviour

For all these reasons evolutionary economists are certainly not advocates of objective value theories nor pointing at some underlying essence for the determination of prices. Their view of value is subjective as in the neo-classical case, but units of selection and the environment in which they operate are very different. Economic agents are believed to adopt rule-guided behaviours, *"often taking the form of relatively invariant routines, whose origin is shaped by the learning history of agents, their pre-existing knowledge, and most likely also their value systems and their prejudices. […] Putting it another way, the behavioural foundations of evolutionary theory rest on learning processes involving imperfect adaptation and mistake-ridden discoveries"* (Dosi & Nelson, 1994).

3.2 Ecology

Contributions on value theory coming from the ecologic field are characterized by the belief, among natural sciences, in the necessity to reintegrate biophysical metrics in evaluation to foster a vision of strong sustainability. This can be described as a view encompassing limited or no substitutability between economic and natural capital, acknowledging the existence of biophysical limits to growth, the so called "scale issue" (Daly, 1992). Ecological approaches are mainly focused on energy, looked by different angles, to explain value from a (biophysical) cost of production point of view. We can split these "energy theories of value" into two main approaches: "embodied energy" and "emergy synthesis".

3.2.1 "Embodied energy" theory of value

These represented an important line of thought in the early days of the inter-disciplinary field known as "Ecological Economics" (Costanza, 1989). "Embodied energy" theories of value have been one of the first scientific attempts to anchor the concept of value to objective biophysical metrics, like energy. Much debate was generated in Ecological Economics in the 1990s about "*whether embodied energy could be related to market value*" (Pirgmaier, 2021). One of the most famous advocates of the relation between exchange value and "embodied energy" was one of Ecological Economics' most influential authors, Robert Costanza. Costanza looked at correlations between market prices of goods and services in dollars in the US economy and energy spent in their production processes. Through his input-output analysis (Costanza, 1980), he was able to show highly positive levels of statistical correlation between energy content and price if energy costs calculation included an estimate of government services and labour costs in energy terms. On the basis of this empirical evidence, he adopted an "embodied energy" theory of economic value, which maintains that "*the value of any good or service to humans is ultimately related to the quantity of energy directly and indirectly used in its production*" (Cleveland, 1999). Costanza claimed that if markets were perfectly functioning, through complex evolutionary processes, prices of goods and services would adjust, in the long run, to levels proportional to their energy content, reflecting what he considered their true costs of production (Cleveland, 1999; Pirgmaier, 2021). In the words of the author: "*There is no inherent conflict between an embodied energy (or energy cost) theory of value and value theories based on utility… Embodied energy values are accurate indicators of market values where markets exist…[…]…markets can be viewed as an efficient energy allocation device that humans have developed to solve the common problem facing all species – survival*" (Costanza, 1980). From this point of view, the problem seems then to adjust markets activity to fix imperfections and incompleteness: policy implications in line with neo-classical recommendations (Cleveland, 1999). This approach makes "embodied energy" analyses very similar to cost benefit analysis, only substituting "marginal utility" with "energy availability" (Pirgmaier, 2021). This is one of the factors which paved the way for the decline in interest towards "embodied energy" value theories. Nowadays this debate is mostly vanished, and these value theories have little support in the scientific community.

3.2.2 The "Emergy synthesis"

The concept of "emergy" was defined by the famous systems ecologist Howard T. Odum starting from 1980s, becoming an available tool in decision making by the end of last century (Odum, 1996). Odum's intuition was to reverse the neo-classical solution to environmental problems (internalization of the externalities), by putting on the contrary the economy on the same basis as the work of the environment and *"externalize the internalities"* (Odum & Odum, 2000). The main difference with previous energy value theories lies in the fact that Odum's concept of "emergy" does not stand for "embodied energy" but for "energy memory" (Odum, 1996; Hornborg, 1998) and is based on a hierarchical view of the various forms of energy, in terms of their quality. Moreover, from a philosophical standpoint, adopting a "donor's side view" (the point of view of the biosphere), Odum's defines a non-anthropocentric, or biocentric, perspective (Gonella et al., 2019; Vihervaara et al., 2019; Franzese et al., 2009, 2014).

Odum's starts by recovering the classical and pre-classical idea that value, or real wealth, *"is the product of work"*, whether of human beings or the biosphere (Odum, 1996). He strongly rejected the use of neo-classical economics tools to assess value in the context of environmental goods (such as contingent valuation based on marginal utility, WTA and WTP), considering them structurally inappropriate. He proposed in fact a contribution-based notion of value (and not scarcity-based), where the value of natural resources is dependent on the biophysical contribution for their generation and not, on the opposite, on their relative scarcity. In the words of the author:

"Ecosystems of the world are threatened because market prices are used to evaluate them. […] money is only paid to people for their contributions, and not to ecosystems. In fact, market values are inverse to contributions. When soils, wood, and other environmental products are abundant, they contribute the most, but market value is small. When environmental products are scarce, the market value is high. Economic valuation, as currently practiced, can never be used appropriately to evaluate environmental capital, its contributions, or its impacts" (Odum & Odum, 2000).

While acknowledging the fact that other biophysical theories of value based on energy have been proposed without much success in the past, especially in the field of Ecological Economics (Burkett, 2003) his conclusion is that such theories failed because they didn't consider the differences among the various forms of energy. In "The Energetic Basis for Valuation of Ecosystem Services" Odum wrote: *"The early evaluations ignored the natural energy hierarchy of the universe in which many joules of one kind must be degraded to generate a few joules of another"* (Odum & Odum, 2000). Therefore, the first thing to do according to Odum is to establish a hierarchy of energy forms based on their *"quality"*, meaning their potential to produce work (i.e., exergy). Hence, the definition of the concept of *"transformity"*emerged , meaning the amount of energy of one kind necessary to obtain one joule of another kind of energy. To be able to compare all the various types of energy according to a common denominator, Odum introduces the so-called*"solar transformity"* (Franzese et al., 2009). The concept of "emergy" expresses *"all numbers in one kind of energy (for example, solar energy) required to produce designated goods and services. Thus, it measures the work of the environment and economy on a common basis"* (Odum & Odum, 2000). In this sense, emergy synthesis can be thought as an "embodied solar energy" theory once every source is accounted for in terms of solar energy directly and indirectly required for its generation. The work, in terms of energy, made by the sun is taken as a sort of universal metric of all work made by both the biosphere and the socio-economic sphere. As stated in (Ulgiati et al., 2011): *"The emergy synthesis method (Odum, 1996) is a technique of quantitative evaluation that determines the environmental value of non-marketed and marketed resources, services, commodities and storages in common units of solar equivalent energy required to make a given product or service. The method is based on principles of energetics (Lotka, 1922), systems theory (von Bertalanffy, 1968) and systems ecology (Odum, 1994b)"*.

3.3 Bioeconomics

While nowadays it is used in a completely different meaning (see for example Viaggi et al., 2021), originally the term "bioeconomics", as conceptualized by his founder Georgescu Roegen, indicated an inter-disciplinary field aimed at developing a new scientific paradigm. The latter could have been able to overcome the weak sustainability view through the integration of economics and biology, founding an economic paradigm rooted in the principles of life sciences (Bobulescu, 2015; Gowdy and Mesner, 1998). At the heart of bioeconomics is the recognition that mankind's survival problem is different from all other species, and *"neither only biological nor only economic. It is bioeconomic"* (Georgescu Roegen, 1975). Georgescu Roegen's originality resides in being against both the neo-classical and the marxian approach, which were considered the main two opposing frameworks of analysis at his times (Georgescu Roegen, 1970).

Another peculiar trait of Roegen is that contrary to other biophysical economists of his times (see for example H. E. Daly, 1993), he never believed in the possibility of a steady-state equilibrium as a sustainable solution for mankind's future. He was in fact a strong proponent of "de-growth" as only possible future path (Georgescu-Roegen, 1977; Missemer, 2018). Using his own words: *"This impossibility of a macro-system not in a state of chaos to be perpetually durable may one day be explicitly recognized by a new thermodynamic law just as the impossibility of perpetual motion once was"* (Georgescu Roegen, 1975). Georgescu Roegen's view of evolution and history as *"permanent struggle in continuously novel forms"*, the opposite of *"a predictable, controllable physico-chemical process"* (Georgescu Roegen, 1975) did not allow him to believe in the possibility of a stable steady state and made him an inspirer of evolutionary thinking.

Georgescu Roegen and Alfred Lotka laid in fact the theoretical groundwork for an economic process embedded in the field of physical biology. This approach can be considered at the roots of later important developments in heterodox economics, such as Evolutionary Economics, the theoretical foundations of Ecological Economics and later also the birth of Econophysics (Melgar-Melgar and Hall, 2020; Rickles, 2007; Schinckus, 2010a). The bioeconomic concept of value is based on energy but differentiates itself from "energy value theories" emerged later in the field of Ecological Economics, of which Georgescu Roegen had always been a strong critic. Against Robert Costanza and others "embodied energy" proponents he moved accusations of reproposing neo-classical reductionism, just in other forms, and labelling them as simply "counting calories" (Martinez-Alier, 2002). Likewise, he labelled H.T. Odum's "emergy" approach as a *"modern dogma of energetics"* (Bobulescu, 2015). Georgescu Roegen's distinctive conception of value is based on energy but at the light of thermodynamical laws, with the application of the concept of "irreversibility" to the economic process to justify its view in terms of thermodynamic processes. As he stated: *"the Entropy Law is the most economic in nature of all natural laws. The economic process, like any other life process, is irreversible (and irrevocably so); hence, it cannot be explained in mechanical terms alone"* (Georgescu Roegen, 1975). According to Roegen, only through the notion of entropy we can discriminate between valuable and not valuable things. The entropy law, acting as a sort of *"taproot of economic scarcity"* (Georgescu Roegen, 1975) captures the qualitative distinction in value between low entropy inputs of resources and high entropy finite products that economists were never able to acknowledge.

Contrarily to theories of value coming from the ecology field, Georgescu Roegen puts more emphasis on matter than on energy in explaining value. He refers to the finite stock of material low entropy as the essential element in mankind's dowry, especially since matter is transformable into energy, but the contrary is not possible. For these reasons, in a closed system like the planet Earth, *"matter matters"* (Georgescu-Roegen, 1977). Ordered material structures are the only "stock" and disposable component in mankind sources of low entropy: the other, sun's energy, is a "flow" beyond our control over time. To use the words of the author: *"accessible material low entropy is by far the most critical element from the bioeconomic viewpoint"* (Georgescu Roegen, 1975). From these beliefs he defined his Fourth Law of Thermodynamics in the attempt to increase the economic significance of the II Law by limiting its range of application to material low entropy. It is also known as the principle of "impossibility of perfect recycling" and can be expressed as following: *"in a closed system, the material entropy must ultimately reach a maximum"* (Georgescu-Roegen, 1977).

The view of the economy by Georgescu Roegen resembles the view of living things by Ilya Prigogine as far from equilibrium open systems or *"dissipative structures"*, which maintain their internal order at the expense of a constant entropic degradation of the environment (Kondepudi & Prigogine, 2015). Accordingly, the radical view of the author is that the economic process consists in basically a process of value destruction, transforming valuable resources (low entropy, available and accessible energy) into waste (high entropy, bound energy). But this process continues to take place because *"the real output of the economic process (or of any life process, for that matter) is not the material flow of waste, but the still mysterious immaterial flux of the enjoyment of life"* (Georgescu Roegen, 1975), at the core of Roegen's view of value (Burkett, 2003; Georgescu Roegen, 1970; Gowdy & Mesner, 1998).

3.4 Econophysics

The neologism "econophysics" derives from the contraction of the terms "economics" and "physics", and *"denotes the activities of physicists who are working on economics problems to test a variety of* *new conceptual approaches deriving from the physical sciences"* (Mantegna et al., 2000). This inter-disciplinary approach originated in 1990s as a field of research dominated by physicists working on economics problems. Even though the "econophysics" approach has been defined only in recent years, contamination between the disciplines of physics and economics has a long story and can be dated back to the origins of the marginalist approach. In particular, the work of Francis Ysidro Edgeworth, (a contemporary of Alfred Marshall), represents the highest point of classical physics influence to the development of mainstream economic methodology (Drakopoulos & Katselidis, 2013), setting the tune for a methodology based on mathematical formalism even in social sciences. The objective of marginal analysis was in fact the systematic mathematization of economic problems in the effort to make economics an exact science like physics, and especially classical mechanics (Mirowski, 1989). In this sense, we can say that physics and economics are profoundly linked since *"Edgeworth's approach dominated the bulk of orthodox economic methodology as the subsequent works of Pareto, Fisher and more recently Samuelson, demonstrate"* (Drakopoulos & Katselidis, 2013). In the more contemporary development of econophysics, on the contrary, the physics scientific ideal re-emerged in the form of a critique of mainstream neo-classical analysis, with objectives similar to the other biophysical approaches. Main differences between the approach of economics and the one of Econophysics, according to the authors of this article, can be summarized in the following (Drakopoulos & Katselidis, 2013; Schinckus, 2010b):

- Methods: the methods of statistical physics are preferred to mechanical models which inspired neo-classics.
- Research goals: rebuttal of neo-classical atomistic view (homo oeconomicus) of individuals and disinterest through micro-foundation; interest in statistical regularities and emerging properties of complex economic systems (scaling laws), which appear only at macro-level.
- Epistemological foundations: empirically founded (ex-post) real data driven approach vs aprioristic assumptions of neo-classical economics (rational choice theory).

For econophysicists, key concepts of the neo-classical value framework such as the assumptions of perfect rationality, perfect competition, utility maximization are axioms without any empirical base, producing an a-priori approach which is not fit to deal with the reality of complex systems. According to (Keen, 2003), *''Pivotal concepts from modern economic theory are empirically and logical flawed. Physicists should not use any of these in econophysics and should be wary of many other models accepted by economists''*. Econophysics acknowledges the fact that economics has basically achieved the complete *"Gaussian reduction of uncertainty"* to the concept of risk using a probabilistic approach, as very well highlighted in Schinckus (2009). Econophysicists object that the systematic reduction of uncertainty to risk leads to an incomplete representation of reality, building economic models not on empirical data but based on "*some non-existent, ideal market''* (Rickles, 2007).

Econophysicists have often referred to the concept of entropy as a metaphor for their modelling of uncertainty: *‘‘entropy is a measure of dispersion, uncertainty, disorder and diversification used in dynamic process, in statistics and information theory, and has been increasingly adopted in financial theory’’* (Dionisio et al., 2006). On these grounds, an original theory of value has been proposed in the field by Ricardo A. Rodríguez and José J. Cáceres-Hernández (Rodríguez & Cáceres-Hernández, 2018). Their view of entropy is not as universal measure of scarcity and value (like Roegen) but as a proxy of the level of socio-economic uncertainty. Starting from the fundamental assumption that *“lack of information (uncertainty) and entropy are identical in essence”*, authors explore hypothesis that information is the primary source of value. According to their “Information Theory of Intrinsic Value” (ITIV), the *“neoclassical interpretation regarding the concurrency of scarcity and price is a typical case of omitted-variable bias due to statistical spuriousness”* (Rodríguez & Cáceres-Hernández, 2018). The third factor connecting the exchange value and scarcity is the concept of *“negentropy”*, or the capability of a good to reduce consumer’s entropy, therefore uncertainty. This capability is deemed to be *“proportional to the embodied information or materialized knowledge”* (Rodríguez & Cáceres-Hernández, 2018). The creation of negentropic capabilities requires enormous amounts of “lost labour” (labour that does not contribute to the production of embodied information because of thermodynamic dispersion) i.e. “production entropy”. By establishing that the primary source of value is “embodied information”, which requires “lost labour” and that it has an opposite relation with system’s entropy, ITIV redefined the neo-classical notion of utility and price formation mechanisms, providing a more *“realistic understanding of economic performance in agreement with the facts that characterize everyday economic activity”*(Rodríguez & Cáceres-Hernández, 2018).

As an output of the literature review on alternative approaches to the concept of value, we propose the following classification through Table 2.

Table 2. Classification of the main heterodox economics and non-economic theories of value in various disciplines and inter-disciplinary approaches.

Discipline or inter-disciplinary approach	Main Authors	Valuation approach	Characteristics of value	Historical context
Evolutionary Economics	Alchian A. Dosi G. Nelson R.R. et al.	Procedural uncertainty, dynamic analysis, biological analogy	Critique of RCT and absence of uncertainty	Early 20th century
Bioeconomics	Georgescu Roegen N.	Low-entropy matter scarcity, enjoyment of life	Objective, anthropocentric	1970s-1980s
Ecological Economics	Costanza R.	“Embodied energy” value theories	Objective, anthropocentric	1980s-1990s
Ecology	Odum H.T.	“Emergy” synthesis	Objective, donor’s side, biocentric	1990s-2000s

Econophysics	Rodriguez R. Cacereces H.J. Schinckus C. et al.	Information Theory of Intrinsic Value (ITIV), “embodied information”, “negentropy”	Synthesis between objective and subjective	21st century

4. Discussion

As very well summarized by Alf Hornborg, biophysical and economic disciplines look at value from secular-old different perspectives and seem sometimes trapped in opposite conceptions, as in a “*dualistic cosmology*” (Hornborg, 1998). While natural sciences try to look for objective foundations for cultural phenomena, in the attempt to subsume economy suggesting that prices reflect biophysical variables, the opposite has been done by economists trying to reduce Nature and all phenomena to subjective experiences. None of these positions renders justice to the complexity of the real world, where economics, ecology and physics, society and nature, cultural and material conditions are “interfused” in the problem of value (Hornborg, 1998). The literature review work undertaken allows us to say that while the mainstream economics view, equating the concepts of market value and price, poses itself as a descriptive theory of value, biophysical approaches are primarily normative. This means they do not describe how value is measured in ordinary life but how it should be measured. All these different perspectives on value share in fact the belief that market prices have an imperfect relation with real value. The latter is, according to them, anchored to some underlying quantity, quality, or essence, which we can measure objectively, escaping the ineliminable subjectivity of neo-classical value framework based on rational agents’ individual preferences (Røpke, 2021).

Clearly distinguishing themselves from economic value theories, biophysical approaches to value share the bulk of their neo-classical critique, but through a comparative analysis we can highlight several differences and points of touch between the economic and the biophysical domain. In this regard, we can start arguing that value theories coming from the ecology field (“embodied energy” and “emergy”) share with Marxian and other classical value theories based on “embodied labour” the belief that value depends on the amount of work performed. In the first case referring to the amount of energy spent, or work made by the biosphere (biophysical metrics), in the second the amount of work invested in the production of a good or the total cost of its attainment (economic metrics). In this sense we can consider “energy theories of value” (ETV) and “labour theories of value” (LTV) to provide similar objections to neo-classical value theory. Even “information theory of intrinsic value” (ITIV) provides a similar objective metric, since value is considered dependent on the amount of lost labour used to convert “embodied information”. ITIV aims also at unifying the two opposing conceptions of value as “subjective” or “objective” integrating the objective metrics on information, uncertainty, and entropy with the recognition of contextual factors and markets functioning (Rodríguez & Cáceres-Hernández, 2018), while this goal is absent in the other biophysical perspectives. By analysing labour from a thermodynamic point of view, ITIV can also distinguish between labour that is converted in embodied information and labour which is lost. This distinction is not present in classical labour theory such as “embodied labour” or “commanded labour” theories of value (LTV), and therefore we can say that ITIV redefines a LTV which is able to defend itself against neo-classical arguments. In fact, the simple neo-classical objection stating that *“goods on which much labor has been expended often have no value, while others, on which little or no labor was expended, have a very high value”* (Menger, 1871) can be easily addressed using the notion of lost labour.

We can trace the origin of biophysical ETV and ITV approaches in the recovery of important aspects of pre-classical notion of value, in particular the physiocratic view centred on the importance of Nature and energy flows. We can recognize, moreover, that the ITIV approach clearly owes many insights to Roegen’s bioeconomic approach. This was the first to define value in thermodynamic terms and was itself based on the will to rediscover pre-classical authors, in clear opposition to classical and neo-classical views (Cleveland, 1999).

The evolutionary line of thought anticipates all the other biophysical approaches through key inter-disciplinary figures (Georgescu Roegen, Schumpeter) and appears as the only heterodox framework still retaining a subjective view of value. But the evolutionary still rejects marginalism and the atomistic view of individuals as rational actors: economies are seen as complex, dynamic systems permanently far from their equilibrium state (Schulz, 2013). In this sense we argue that evolutionary analysis shares its core view with bioeconomics, aiming at an analogous methodological integration of economics and life sciences disciplines. Their critique is directed to neo-classical economics mathematical formalism based on classical physics, with the related atomistic view of the individual as “homo oeconomicus” characterized by stable exogenous preferences and rational expectations. The evolutionary conception assumes, on the contrary, that individuals are not the fundamental unit of analysis, but constantly influenced by each other’s choices in a dynamic environment, dominated by institutions. Bioeconomics and evolutionary thinking will be at the foundations of inter-disciplinary approaches such as Ecological Economics.

As pointed out in Melgar-Melgar & Hall (2020), we can find a common denominator in these alternative, biophysical approaches in the need to return to more inclusive and inter-disciplinary methodologies of valuation, given the presence of what are considered important fallacies in economic analysis. Whether it is the energy invested, energy memory, the material low entropy degraded or the negentropic information content embodied, these theories aim to highlight that we need biophysical metrics to account for dimensions of value that will be otherwise neglected by economics. Economic value theories are never embedded in a view acknowledging the finite nature of available biophysical resources (environmental space), nor they acknowledge the presence of non-reducible value dimensions (economic and biophysical). The belief in unlimited growth, and the acritical consideration of economic growth as a “positive sum game” (Hornborg, 2009) appears instrumental to the objective of continuing to perpetuate unjust processes of exploitation and appropriation as if they were fair. This has been well highlighted in "ecologically unequal exchange" literature, which deals precisely with inequality issues coming from the equalization of biophysical value flows and economic flows (Dorninger et al., 2021; Hornborg, 2019; Røpke, 2021).

5. Conclusions

A role for biophysical perspectives in valuation, as already highlighted, certainly exists, and deserves higher consideration, as inter-disciplinary research areas tend to underline. Studies have been already conducted in these fields which compare value assessments through evaluation techniques considering biophysical metrics, such as material flow analysis and emergy analysis, with traditional monetary values assessment. In essence, biophysical perspectives can provide essential information besides monetary exchanges, accounting for different and informative dimensions which complement the exchange values with use value and holistic considerations. This reveals particularly true when considering complex systems interactions, as highlighted in literature about "ecologically unequal exchange", which describes the complexity of the dynamics triggered by international trade of natural resources between Core and Periphery. Sustainability issues linked with these value problematics are recognized and explored up to today, also in very important journals.

The knowledge provided by biophysical perspectives could help policy makers designing new processes of evaluation more fit to 21st century sustainability challenges we have to face. Valuation is in fact a concept much more important than the abstract notion of value and the latter is not a shadow property of objects, waiting to be highlighted. On the contrary, values are actively assigned to objects according to different criteria, practices, and methodologies of valuation. It is therefore on the latter that we must focus. In the words of the famous ecological economist Ropke, mentioned at the beginning of the paper: *"value is never given as a substance or essence, but it can be created (in the sense of constructed) in different processes of valuation, sometimes in markets where the processes result in prices, sometimes in cost-benefit or multi-criteria analyses, which result in other types of assessments"*.

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