Integration of approaches to social metabolism into democratic economic planning models

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Abstract: The integration of environmental issues in democratic economic planning models is the object of ongoing debates. Environmental factors cannot be only reduced to economic indicators, rendering economic models unable to properly account for ecological limits. By focusing on our societies' biophysical needs, the concept of social metabolism opens new avenues to answer such problems. This paper presents two sociometabolic models and their limits to explore how this perspective could inform democratic economic planning models.

Key words:
Social Metabolism, Democratic Economic Planning, Ecological Economics

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1. Introduction[1]

The three most debated models of democratic economic planning – Pat Devine and Fikret Adaman's negotiated coordination, Michael Albert and Robin Hahnel's participatory economic and Paul Cockshott and Allen Cottrell's computerized central planning[2] - were first designed between 1988 and 1993. Even though environmental preoccupations were growing at the time, they were far from the prevalence they currently hold in public spaces. This gives context as to why the first instances of these models had little to say about the environment.

The ecological crisis humanity is currently facing imposes a new criterion to judge models of democratic economic planning. Not only should they be better suited at allocating resources, but they must also foster a more harmonious way for humanity to inhabit the planet's ecosystems. Most of the models' proponents have shown interest in these new priorities and have publicly shared their thoughts on the question, some of them going so far as to modify their models with the ecological question in mind.

A collective of authors[3] argued that even though these reflections and adaptations were welcome, they were still insufficient to fully grasp the scale of ecological issues. According to them, postcapitalist models should be able to measure and act on the scale of the economy, considering multifactorial dimensions in their decision-making processes, something the three models were not designed to do. The collective of authors also pointed out that current research on social metabolism could inspire further adaptations of democratic economic planning models.

Building on this argument, the present article goes the other way around and evaluates which approach to social metabolism could prove useful in a democratically planned postcapitalist setting. The issue at hand reveals to be rather complex as it not only requires to engage two distinct theoretical movements in fields they have yet to fully make their own - ecological issues for democratic planning and political critique for social metabolism - but it also reveals the meaningful tension linking these unrealized aspects. A secondary issue therein lies in the proper conceptualization, and further elaboration, of this relation, while still accounting for what remains to be built. Here we argue that, beyond empirical data which is central to both social metabolism and democratic planning, the integration of social hermeneutics as a method through which generate meaning from biophysical and cultural data might prove useful to link both approaches. These are rather large questions, which cannot all be answered here. We thus restrict

[1] This article draws on research supported by the Social Sciences and Humanities Research Council.
[2] Those who want a summary of these models can refer to Legault and Tremblay-Pepin, "A brief sketch".
[3] Planning for Entropy, "Democratic Economic Planning."

this paper to the perspective of democratic economic planning and how social metabolism can better inform its evolution towards environmental thought.

The next two sections (2 and 3) present both theories of democratic economic planning and social metabolism in order to provide a common baseline for our paper. We then address the aforementioned tension lying between empirical environmental data and political integration by first exploring how it manifests in the viennese school of social ecology (section 4) and how these issues have since been at least partially addressed (section 5). This will open up to a discussion looping back to democratic economic planning and how to conceptualize its integration of sociometabolic research in its future configurations (section 6).

2. Ecological institutions and issues with ecology in democratic economic planning

Planning for Entropy's 2022 article recognized that there were some ecological elements - and in some cases even institutions - present in the models of Devine and Adaman, Cockshott and Cottrell, and Albert and Hahnel. For example Devine and Adaman's negotiated coordination submits all major investment decisions to a democratic process in which environmental groups take part. It also imposes a rental on natural resources based on its rate of depletion. On the other hand, in Cockshott and Cottrell's model, any decision that could potentially impact the environment is deemed political and should be taken via referendum.

However, we consider that Robin Hahnel's recent works on participatory economics have furthered the environmental question the most. Hahnel designed a *pollution demand*[4] *revealing mechanism* that gives the opportunity to a Community of Affected Parties (CAP) to either forbid the usage of a pollutant on a territory where it would affect them or to determine a compensation in consumption credit to be dispensed by the polluter. He also designed long-term planning mechanisms, allowing society the opportunity to focus on broader social change, what he called investment planning and development planning[5]. One of the development plans that must be produced concerns the environment and how in the long term resource extraction and pollution emission should be managed. To build such a plan, a clear idea of the environmental situation is needed. In *Democratic economic planning*, Hahnel implemented in participatory economics a Ministry of the Environment that "knows best what it costs to protect/enhance the environment"[6]. The environmental development plan is designed by the federation of consumers and the federation of producers with help from this ministry and proposes long term goals that

[4] Robin Hahnel first called this institution a pollution damage revealing mechanism. We agree with the author that the name given in his most recent publication where he replaced damage by demand is more appropriate. It is clear to us that this process does not reveal damage done by pollution, but only how much people affected by it want to be affected by it and at what cost.

[5] Hahnel, *Of the people, by the people,* 120-121. Hahnel and Kerkhoff, "Integrating Investment and Annual Planning," 226-233.

[6] Hahnel, *Democratic Economic Planning*, 265.

will impose constraints on annual planning, production and consumption processes. This plan must be submitted to a referendum or a vote in a representative assembly.

Even with these elements present, we contend that the models of democratic economic planning rely on valuation systems and/or decision making processes that cannot take into account the appropriate information nor reach the necessary goals for humanity to achieve a balanced relationship with its environment.

To understand the nature of the problems we see with those models, we will use criteria proposed by Simon Tremblay-Pepin to evaluate and compare postcapitalist economic models: organization, regulation, limitation, formalization and scope.[7] Three criteria stand out specifically when thinking about the relationship between human society and the environment: regulation, limitation and scope. We briefly examine these criteria in the remainder of this section.

Regulation is a criterion taken from David Laibman's work[8] and pertains to decision-making processes. On the spectrum of regulation, a quantitative-digital pole, where decisions are based on numbers and calculi, is opposed to a qualitative-verbal pole, depending on words and arguments. Situating a model within the regulation spectrum will determine whether more weight is to be attributed to quantitative or qualitative indicators. The multiplicity of indicators required by ecological economics to dress a proper empirical portrait thus lead to the issue of reaching the right balance between qualitative and quantitative data.

Limitation addresses the delicate issue of limiting democratic institutions' theoretically limitless potential of action while also preserving their autonomy. Being founded on the autonomy of the human collective, democracy has virtually no external limits and remains solely bound by human decisions. Here, the limitation spectrum opposes objective constraints to human volition: while the planet's sustainable ecology depends upon strict boundaries to human action, the imposition of outside limits to the democratic process infringes upon its very foundations. The issue then lies in the kind of limitations the democratic model can support.

Scope establishes what kind of problem is to be discussed by which actors of the economic system. On the scope spectrum we find broad issues at one end and specific problems at the other. Democratic planning models are supposed to make humans fully conscious of the consequences of their economic decisions. Therefore, they must not only make decisions about what they want to do as workers and consumers trying to solve the specific problems of their daily lives. But they also need to be able to choose what general direction society should take. This is particularly true about ecological questions linking local behavior to global

[7] Tremblay-Pepin, "Five criteria"
[8] Laibman, "Multilevel Democratic Iterative Coordination"

consequences. How can we make relevant decisions on questions we can act on, without being centered only on our daily economic activities?

These criteria are essential when making choices about ecological questions for a postcapitalist society. But for the moment, existing democratic planning models have not reached the necessary balance for the criteria. For the regulation criteria they either put too much faith in purely quantitative data, or believe every complex political problem would be solvable in political assemblies, through discussion and negotiation. As for limitation, none of the models has developed a way either to understand what are the planetary limits nor a process to modify our economic choice when we reach them. About scope, even if the models possess (or have just added) some institution to deal with broader issues, the scale of the economy itself is never discussed as a central matter.

Our aim, in the coming sections, will be to explore ways to supplement democratic planning models through social metabolism to find a better balance inside the spectra of those criteria. We will first present the approaches to social metabolism to see in what ways their integration could better postcapitalist models.

3. Social metabolism: studying the biophysical patterns of societies

The analogy of a 'social metabolism' is used to describe the biophysical patterns of material and energy flows necessary for the operation and maintenance of societies, namely service-providing and social reproduction. Similarly to a body that ingests nutrients, processes them, develops according to them, and then releases them, societies are complex structures that depend on continuous inputs of matter and energy, that are transformed, consumed or stocked, and eventually rejected into the natural environment. At the basis of this concept lies the understanding that a society is made of complex biophysical and socio-cultural systems which reproduce, interact and co-evolve with each other. Social metabolism thus evokes the world of ecological economics. Indeed, a society's metabolism is defined by its biophysical throughput, which ensures its innate biophysical equilibrium. This supersedes the idea of an equilibrium realized through exchanges of value, typical of classical economics, both by (re)introducing societies to their natural dependency on biophysical cycles and by first putting the emphasis on a society's needs instead of a disembedded economic system's well being. Beyond its analogy with biophysical systems, the specific configurations of a society's metabolism, its material conditions so to speak, are always socially and historically constructed. They are prone to evolve with time, through innovations and social conflict.

Finding its origins in the writings of Marx and Engels[9], it was not until the 1960s – with the work of Ayres and Kneese[10] – that the study of social metabolism (also named socio-economic

[9] Marx and Engels, "Capital 1."
[10] Ayres and Kneese, "Production, consumption, and externalities".

metabolism (SEM), societal metabolism or industrial metabolism)[11] generated greater interest. In the last decades, as the concept gained in popularity and the body of empirical socio-metabolic studies grew, so did the amount of theoretical approaches[12]. For example, Gerber and Scheidel[13] distinguish models of social metabolism based on their compatibility with a substantive analysis, meaning that economics in this context defines the processes through which the physical environment sustains living beings. They propose MEFA (Material and Energy Flow Analyses) and MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) as two models which conceptual frameworks allow for a substantive analysis of economic processes. These provide an analysis of the economy in its complex and systemic interactions with biophysical ecosystems, and integrate units of value different from the sole monetary value. In the context of this research, these models seem best suited to inform the discussion on democratic economic planning, which is why they will be presented in the next sections.

3.1. Material and Energy Flows Analyses (MEFA)

MEFA is an accounting framework developed by the Vienna school of social metabolism, centered around Marina Fischer-Kowalski since 1986.[14] This methodology is used to identify in quantitative terms the throughput of material and energetic flows required each year to sustain and reproduce the biophysical structure of a given society.[15] Two boundaries are to be identified: the one that separates the socio-economic system (such as a national economy) from the biophysical environment, and the one between different socio-economic systems, connected through the imports and exports flowing as inputs and outputs into their systems. MEFA accounts for all the flows entering and exiting the social system through these system boundaries. On the other hand, internal flows are not considered nor represented by MEFA indicators – something that is referred to as the black-box, see below.[16]

At the core of the MEFA framework is the compatibility between the economic system of national accounts and the material and energetic flow accounting. Since the 2000s, MEFA accounting has been included in national environmental statistics by Eurostat and the UNEP, and research funding from international institutions have supported the continuous improvement of MEFA methods. This complementarity between monetary and biophysical accounting schemes, along with the efforts for harmonization of methodological procedures and data collection, and the publications of accounting guides for each scale of study, have favored the widespread use of

[11] The model MEFA usually uses the wording “social metabolism”, and MuSIASEM “societal” or “socio-economic metabolism”. We will use them accordingly in the description of the models, and as synonyms in the rest of the paper.

[12] We identify the four following: 1) Input-Output Analysis (IOA) with its extensions Environmentally Extended Input-Output (EE-IO) and Multi-Regional Input-Output (MR-IO), 2) Life-Cycle Analysis (LCA), 3) Material and Energy Flow Analyses (MEFA) comprised of Material Flow Analyses (MFA) and Energy Flow Analyses (EFA), and 4) Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM)

[13] Gerber and Scheidel, “In Search of Substantive Economics”.

[14] Fischer-Kowalski and Weisz, “The Archipelago of Social Ecology and the Island of the Vienna School”.

[15] Fischer-Kowalski and Erb, “Core Concepts and Heuristics”.

[16] Fischer-Kowalski et al., “Methodology and Indicators of Economy-Wide Material Flow Accounting”.

MEFA methods. Several guidelines and manuals exist at the local level[17], at the national economy-wide level[18], and at the global level.[19]

The MEFA framework uses a stock-flow approach, where stocks refer to human population, controlled livestock and domestic animals, built environment (infrastructure and buildings) and artifacts (machinery and durable consumer goods), and flows refer to energy and materials. A stock is a component of a social system that needs to be reproduced for the system to maintain itself. It is measured as a quantity per point in time, whereas flows are measured as quantities per time period.[20] The maintenance and expansion of stocks is sustained by the matter and energy entering the system as inputs and exiting as outputs: these are the flows. The input side of flows is composed of domestic material extraction (DE), imports and input balancing items. DE, for example, accounts for the annual quantity of raw materials extracted (solid, liquid, gaseous) entering the socio-economic system to be processed, transformed, or consumed. These materials, acquiring a value as they enter the economic system, are "used flows". In contrast, unused flows consist of the extracted matter remaining outside of the socio-economic system boundary. Data on DE only includes used material flows if not otherwise specified. The other side of the input – output balanced equation are output flows, composed of domestic processed output (wastes), exports and output balancing items. Data on output flows is still largely uncovered (except for exports) since most applications of MEFA focusses on input flows. This is due to the fact that data on raw materials and imports is much easier to access, on the one hand because there are less categories of raw materials entering the social system than categories of waste exiting it, and on the other hand because economic statistics on resource inputs are more complete than those for output flows.[21]

Compilations of such accounts give good indications about flows crossing the system boundaries. In contrast, information about the way material and energy flow *within* the system (e.g. inter-industry exchanges of products) is not available in MEFA studies. This implies that, while the crossing of the system's boundaries is well analyzed, the internal functioning of the system is mostly treated as a black box[22]. Net additions to stocks is a supplementary indicator determining the amount of matter of a yearly flow's throughput an economy immobilizes in its stocks. Concretely, this quantity translates to an economy's growing infrastructures, but it can also be interpreted as a temporarily motionless flow. Indeed, whether the process takes one or fifty years, when a stock's life cycle ends, net additions are converted back to flowing outputs.

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[17] Singh et al., *Local Studies Manual*.
[18] Krausmann et al., "Economy-wide Material Flow Accounting. Introduction and Guide. Version 1.2"; European Commission. Statistical Office of the European Union., *Economy-Wide Material Flow Accounts Handbook*; UNEP, *The Use of Natural Resources in the Economy*.
[19] Schaffartzik et al., "The Global Metabolic Transition".
[20] Krausmann et al., "Economy-wide Material Flow Accounting. Introduction and Guide. Version 1.2". p. 11.
[21] Krausmann et al., "Material Flow Accounting"; UNEP, *The Use of Natural Resources in the Economy*.
[22] It is worth noting that input output analyses (IOA) and environmentally extended IOAs (EE-IOA) both offer alternative methods better suited to internal accounting and can often be complementary to MEFA data.

In recent years, MEFA has been expanded with the Material Inputs, Stocks and Outputs model (MISO), a dynamic top-down inflow driven model. This new model, proposed by Wiedenhofer et al., aims at incorporating the role of in-use material stocks of manufactured capital, and quantifying all end-of-life waste with recycling potential.[23] To be implemented, the MISO model requires long-term material flow data – which is usually available for the national and global level. It bolsters MEFA by estimating inflows and outflows resulting from societal stock use and upkeep, putting in focus the innate tension in societies' reliance on stocks to provide services. On that subject, recent studies have further emphasized the capacity for stocks to generate considerable inertia in regards to a society's ability to move away from unsustainable practices. Stocks' capacity to lock-in both practices and flows over a long period of time[24] thus reveal the need for planning endeavors to account for expansive long-time effects when exploring investment avenues. In that sense, MISO's use of simulation scenarios could be an interesting path to consider for democratic economic planning[25]...

3.2. Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM)

The MuSIASEM framework was developed by the "Barcelona school of societal metabolism" around Mario Giampietro and Kozo Mayumi. It emerged in the 1990s with the aim of analyzing the hierarchical structures of the different dimensions of a system (economic, social, biophysical) across multiple space-time scales. It complements sustainability studies with concepts from the theories of complex systems and bioeconomics, such as multi-purpose grammar, Georgescu-Roegen's flow-fund model, autopoietic systems and impredicative loop analysis.[26] The model gives an overview of the impact and interference that the material and energy flows induced by human activity have on the material and energy flows emerging from natural ecosystems.[27]

According to Giampietro et al.[28], there are key theoretical characteristics that any sociometabolic study should involve. At the stage of pre-analytical identification of the object of research, one needs to identify: 1) what is the identity of the system studied and 2) what are the functions of the system. To answer these questions, the researcher needs to identify the external constraints, that is, the inward and outward flows, and the internal constraints, that is, the size and functions of the system's compartments.[29] Studying social metabolism is not only a question of how much

[23] Wiedenhofer et al., "Integrating Material Stock Dynamics Into Economy-Wide Material Flow Accounting".
[24] Seto et al., "Carbon Lock-In: Types, Causes, and Policy Implications".
[25] Traditional MEFA, in contrast, are designed to conduct ex-post analyses of social metabolism. The MISO model was already used to explore future resource requirements, waste, and emissions: see for example Wiedenhofer et al. (2019) and Krausmann et al. (2020).
[26] Giampietro and Bukkens, "Analogy between Sudoku and the Multi-Scale Integrated Analysis of Societal Metabolism".
[27] Giampietro, Mayumi, and Ramos-Martin, "Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) ".
[28] Giampietro, *The Metabolic Pattern of Societies*.
[29] Giampietro.

material and energy flows through the system, but also how the system interacts and processes these flows, and how the system evolves along with them. A sociometabolic study is thus one that analyzes the identity of a system, the identity of the flows going through this system, and the way these identities function, adapt and evolve together.

Inspired by the work of Nicholas Georgescu-Roegen, the MuSIASEM framework applies his fund-flow model to represent the processes of production and consumption of goods and services in biophysical terms. In this model, a fund is a component of the system that is maintained the same throughout the economic process and that participates in the transformation of input flows into output flows. It conserves its definition of converter on the time scale of the analysis. Fund elements bear two key characteristics: they have a specified, limited rate of use and they experience a periodical renewal. Examples of funds are people, technological capital, managed land and total available land. Although MuSIASEM's definition of funds partly overlaps MEFA's definition of stocks, funds are more explicitly active forces of their system, as they provide the services necessary to transform input flows into output flows. The concept of flow refers to an element that is created (e.g., a new product) or consumed (e.g., fossil fuels) during the economic process. Examples of flow elements are energy, food, water, and money. The fund-flow model helps in defining the identities of the system: the fund elements can be used to answer the question "what the system is", and the flow elements define "what the system does". Two factors affect the pace of these flows: the availability of required resources in the environment (external factor) and the existing technology to process and convert the flow (internal factor).[30] MuSIASEM finally presents a series of flow/fund ratios, that give further information about the rate (per hour of human activity), the density (per hectare of managed land), and the intensity (per watt of power capacity) of the flows across the system's hierarchical levels.[31]

Both MEFA and MuSIASEM offer a methodology to assess the metabolism of a given system – usually a society. Historically, the two schools of thought have evolved separately, with little interaction between them. This has resulted in two conceptually different frameworks, with their own strengths and weaknesses. Recently, authors have discussed where the models could meet and strengthen each other, yet this discussion is still in its infancy.[32] In the discussion about democratic economic planning, those models are interesting for their substantive analysis of economic processes. These frameworks allow for a multidimensional analysis of nature-society-economy interactions by including systemic, biophysical and politico-institutional dimensions, and a diversity of accounting indicators.

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[30] Giampietro, Mayumi, and Ramos-Martin, "Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) "; Gerber and Scheidel, "In Search of Substantive Economics".
[31] Giampietro and Bukkens, "Analogy between Sudoku and the Multi-Scale Integrated Analysis of Societal Metabolism".
[32] Gerber and Scheidel, "In Search of Substantive Economics"; Fraňková, Haas, and Singh, *Socio-Metabolic Perspectives on the Sustainability of Local Food Systems*.

Of the many challenges beset upon democratic economic planning, the need for a proper conjugation of multiple diverging discourses and ontologies might be one of its most complex. Beyond specialized committees and sectoral associations, the need remains strong for a method through which assemble disparate and seemingly incompatible elements. Through its interdisciplinary nature, sociometabolic research has dealt with similar problems for a long time[33]. The interrelation between culture and nature, or between societies and their environment, has led to epistemological difficulties when, for example, sociological hermeneutics have had to coexist with biophysical data. As previously mentioned, we believe that a similar tension exists between democratic economic planning and its new environmental objectives. A better understanding of how social metabolism has developed its methods around this issue will prove useful for our reflections. We expound on these ideas in the next sections.

4. Social metabolism's interdisciplinary tensions

Up until recently, metabolic research's delving into social analysis has remained relatively limited. In both MEFA and MuSIASEM's cases, this can mostly be explained, upstream, by the reliance on accounting data and material analyses sharing limited connections with sociological data and, downstream, by the comprehensive results of these same analyses, eclipsing the need for more varied approaches, especially in the form of social research. Whether it be through comprehensive representations of current trends, in the case of various MEFA models[34], or through insightful predictions in the case of MuSIASEM[35] and MISO[36], metabolic research remains a field mostly focused on physical matter in which humans and society play restricted roles.

Of course, here, social analyses can be beneficial to understand and represent the specific relations a social configuration maintains with its conjoint flows. This can lead to deeper comparisons between localized metabolisms, focusing on subjects ranging from labor relations[37] and food regimes[38] to analyses of global and international inequalities.[39] This use of social parameters can also lead to interesting interpretations[40] of the social relations structuring social metabolisms. But metabolic research only requires sociological analyses up to a certain point;

[33] Fischer-Kowalski and Weisz, "The Archipelago of Social Ecology and the Island of the Vienna School".
[34] Dorninger et al., "Global Patterns of Ecologically Unequal Exchange"; Haberl et al., "Contributions of Sociometabolic Research to Sustainability Science".
[35] Giampietro, Sorman, and Gamboa, "Using the MuSIASEM Approach to Study Metabolic Patterns of Modern Societies".
[36] Krausmann, Wiedenhofer, and Haberl, "Growing Stocks of Buildings, Infrastructures and Machinery as Key Challenge for Compliance with Climate Targets".
[37] Haas and Andarge, "More Energy and Less Work, but New Crises".
[38] Krausmann and Langthaler, "Food Regimes and Their Trade Links".
[39] Schaffartzik, Duro, and Krausmann, "Global Appropriation of Resources Causes High International Material Inequality – Growth Is Not the Solution"; Mayer, Haas, and Wiedenhofer, "How Countries' Resource Use History Matters for Human Well-Being – An Investigation of Global Patterns in Cumulative Material Flows from 1950 to 2010".
[40] Fischer-Kowalski and Schaffartzik, "Energy Availability and Energy Sources as Determinants of Societal Development in a Long-Term Perspective".

there comes a point where hermenutics need to give way to quantifiable data. MuSIASEM will, for example, account for multiple demographic and societal specificities relating to culture (consumption habits, average work hours, retirement age) to more closely model the analyzed society, but those will always remain in service of producing better biophysical data.[41]

While there exists in social sciences a wide variety of mixed models allowing for quantitative and qualitative methods to coexist, very few of those lead to accounting models comparable in scope and complexity to MEFA or MuSIASEM. Some attempts from the Vienna School have tried to use metabolic research to push sociological analysis further, with mixed results. For example, by linking the history of social unrest to breakthroughs in the access to fossil fuels, Fischer-Kowalski et al. tried to offer an interesting, but lacking, framework through which interpret the relationships between energy and societal configurations.[42] The limits of such analyses ultimately come down to the difficulty to transcend ontological divides between the metabolic approach, focused on physical relations, and sociological hermeneutics which can never truly translate to purely physical, quantifiable data. This is most prominent, conversely, when metabolic research provides sociological explanations for humans' influences on metabolism. The role humans consistently play in historical metabolic transformations, while undeniable[43], usually lead to teleologic assumptions and simplified cause-effect scenarios in which new technologies lead to increased complexity, moving towards increasingly material-intensive metabolisms.[44] Here, the role of social relations stems from the understanding that human actors are at the center of these processes. This opens metabolic research to social analyses, without necessarily advocating for a deeper integration of social dimensions to material accounting models. Instead of achieving a more pronounced integration of the two ontological models, social metabolism is thus more inclined to foster a form of simple cohabitation.[45]

This explains in part the fragile state sociological analysis occupies in metabolic research, but it also hints at its irreducible quality as a distinct field. By tying sociological analysis to a mostly physical framework, social metabolism has limited its analytical range to much of its detriment. But sociological analyses are still crucial to achieve the field's more political goals.[46] More than a simple accounting method, social ecology aims to inform socioeconomic and environmental policy by providing a methodologically sound systemic analysis of societies. Evidently, these

[41] Giampietro, Sorman, and Gamboa, "Using the MuSIASEM Approach to Study Metabolic Patterns of Modern Societies".
[42] Fischer-Kowalski et al., "Energy Transitions and Social Revolutions".
[43] Fischer-Kowalski and Schaffartzik, "Energy Availability and Energy Sources as Determinants of Societal Development in a Long-Term Perspective".
[44] Such processes find echoes with Joseph Tainter's understanding of societal collapse (Tainter, 2006) in which the unavoidable complexification of societies through problem-management demand increasing energetic and material resources. Diminishing returns in problem-solving would then ultimately lead to societal collapse.
[45] Such problems have been recognized by the Viennese school of social ecology (Fischer-Kowalski & Weisz, 2017), but remained unaddressed until recently (Plank et al., 2021).
[46] Fischer-Kowalski and Weisz, "The Archipelago of Social Ecology and the Island of the Vienna School".

goals echoe back to democratic economic planning's own goals as a political system, illustrating how both movements are at their closest point where they remain the most incomplete.

But social analyses can offer even more diversified tools. On that matter, social hermeneutics allow for deeper explorations, not only of how, mechanically speaking, societies generate meaning out of their metabolic relations, but also of how this understanding can inform, in turn, political positioning relating to this knowledge. What emerges is that such analyses cannot be limited to simple physical frameworks, or, to an insufficient acknowledgment of the sociologic specificities at play. Failing to properly engage with the dialectical nature of social metabolism's epistemological tensions, the current debate will remain sterile. In this context, the recent work in Nexus methods, originating from the Vienna School of Social Ecology[47], offers a welcome improvement to metabolic research.

5. Integration of social dynamics through Nexus approaches

Sociological developments in metabolic research have been in the works for a few years, addressing interrogations regarding the ways in which metabolic models could actively lead to sociological transformations.[48] For the Viennese school of social ecology, this has remained a problem in large part due to the reliance on Luhmann's sociology of systems[49] and its irreconcilable incompatibilities with social metabolism's more reflexive goals.[50] In effect, social metabolism has relied for a long time on a social theory ill-equipped to accurately conceptualize the role of human agency.[51] This is especially important in the context of democratic economic planning because profound understandings of both societal configurations and individual agency are tantamount to shaping a functioning democratic system. In addition, the planning and enacting of a transition towards a new socioeconomic system evidently benefit from in-depth reflexive frameworks. Recent papers[52] have thankfully begun to address these issues by introducing the concept of Stock-Flow-Services Nexus (SFS-nexus) to further bridge the gap between social sciences and metabolic research.[53]

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[47] As far as we are aware, these issues have not been addressed by proponents of the MuSIASEM model.
[48] Hausknost et al., " 'Society Can't Move So Much As a Chair!'—Systems, Structures and Actors in Social Ecology".
[49] Systems are defined by their difference to a larger environment. This is realized through the system's mode of operation, which coordinates significant elements in a way that is specific to the system. Systems can be composed of subsystems or can find in their environment other systems to communicate with, but the crucial factor is each system's functional autonomy. Indeed, a system's mode of operation is only able to generate change through itself.
[50] Hausknost et al., " 'Society Can't Move So Much As a Chair!'—Systems, Structures and Actors in Social Ecology"; Fischer-Kowalski and Weisz, "The Archipelago of Social Ecology and the Island of the Vienna School"; Weisz and Haas, "Health Through Socioecological Lenses—A Case for Sustainable Hospitals".
[51] Hausknost et al., " 'Society Can't Move So Much As a Chair!'—Systems, Structures and Actors in Social Ecology".
[52] Plank et al., "Doing More with Less"; Görg et al., "Scrutinizing the Great Acceleration"; Görg et al., "Challenges for Social-Ecological Transformations".
[53] Plank et al., "Doing More with Less"; Haberl et al., "Stocks, Flows, Services and Practices".

The SFS-nexus builds on the metabolic idea that physical stocks determine a society's material flows and its global resource use. It is used to consider how stocks, by processing specific material and energetic flows, provide societies with specific services, contributing to general wellbeing. This shows how resource intensive need-satisfaction processes can be: services are produced through flow consumption; the quality and availability of the former being highly determined by the latter. Societal need-satisfaction then relies on subsequent sociological analysis to adequately conceptualize services "as a set of benefits or wellbeing contributions".[54] That said, service-providing is not to be interpreted as a solely positive function of stocks, considering how it often comes with negative side-effects. For example, an incinerator constitutes a stock geared towards domestic waste disposal. But this crucial service comes at the cost of a diminution in air quality and an increased flow of domestic wastes, often induced directly by economical needs to use the stock at its full capacity. While this method goes further in trying to bridge present ontological gaps in social metabolism, attempts at quantifying service-providing through the SFS Nexus framework encounter similar issues as the ones noted by Zeng et al.[55], namely, the difficulty in accounting for the high diversity of cultural distinctions and contexts.[56] Though complex issues, the interdisciplinarity of nexus frameworks allows the accounting of contradicting ontologies without subsuming parts of the object. This also allows for improved flexibility, as exemplified by the Stock-Flow-Practice nexus (SFP-nexus), which prioritizes qualitative analyses to conceptualize how social practices determine the demand for specific flows and stocks.[57] While an inversion of the SFS-nexus approach[58], the SFP-nexus is in no way in contradiction with the former, serving as a complementary tool to depict social relations to stocks.

More importantly, by allowing an increased focus on social relations, the SFS-nexus opens metabolic research to interpretations of potential conflicts in socioecological transition. Developing on the negative impacts imposed by stock usage and service-providing, it is possible to account for the unequal access to services provided and the subsequent distribution of negative impacts. Conflicts around access to wellbeing services and the mediation of associated costs imposed on populations all depend on larger power relations, which in turn find their roots in societal structures such as the state, the economy and culture.[59] These structures have been further analyzed by the "provisioning systems" framework which aims to detail the social structures linking biophysical systems to human needs. This means to understand how political

[54] Haberl et al., "Stocks, Flows, Services and Practices".
[55] Zeng et al., "Environmental Destruction Not Avoided with the Sustainable Development Goals".
[56] Haberl et al., "Stocks, Flows, Services and Practices".
[57] Haberl et al.
[58] The distinction of both models lies in how we choose to define the driving factors of stock-flow relations. While the SFS-nexus develops a holistic understanding of the services offered and expected, putting focus on societal structures, the SFP-nexus analyzes how individuals' habits and modes of living drive demand for specific flows and stocks. This methodological rift harkens back to early epistemological divisions in sociology between quantitative and qualitative analyses. Here, the SFS-nexus relies on a top-down analysis while the SFP-nexus opts for the bottom-up alternative.
[59] Plank et al., "Doing More with Less".

and social systems coordinate relations between "infrastructure, technology, land use, supply chains on the one hand and state, markets, communities, institutions, norms, culture and distribution on the other hand".[60] Such a complex framework is the only kind of answer able to properly satisfy explorations in the societal particularities shaping SFS-nexuses. In turn, this complexification is a good way for metabolic data to inform new meanings by not only questioning what societal needs are satisfied, but also determining how those needs are socially created and defined[61], how they contribute to social and biophysical deterioration and how they can be further politicized through the accentuation of their conflictual nature.

This interpretation leads to a complex dialectic, structuring natural resource and actor relations in a way where physical stocks serve as much to transform and provide goods and services to actors as they contribute to the generation of actors by way of generating needs and expectations in said actors. This leads to a pragmatic conceptualization of society-nature relations in which society's role is to define the actors' more pressing needs and how to best satisfy them. These processes are constrained, socially, on the one hand, by the actors' access to knowledge and technologies and by the inertia imposed by practices and institutions and, on the other hand, physically, by various biophysical limits (e.g., scale and durability of possible service-providing) for which standard metabolic research is currently the more reliable source of information.

6. Integration of approaches to social metabolism into democratic economic planning

The dialectical relation binding humans and nature is at the core of social metabolism, but, as evoked above, we have remained relatively unable to properly assess this relation until now. Here, we suggest that the resulting synthesis of this dialectic lies in a mediating factor in which both social metabolism and democratic planning might find a common answer, namely, the interpretative capacity of humans to generate meaning from information. This recourse to hermeneutics might at first glance seem as too simple a solution for the complex predicament that are social relations to nature, but at the same time, it is evident that any matter leading to democratic decision-making will require the derivation of meaning from data, in turn allowing for social action. Interpretative processes are rooted in the dialectical processes animating and structuring social metabolism; they manifest through human interactions with the world and thus cannot be restricted to a structure derived from empirical data. The democratic nature of planning models offer a way to render (at least partly) conscious the generation of actors and needs through their own experience, but to act upon this knowledge, actors remain to be made meaningfully aware of the metabolic dimension of their existences. This cannot solely be realized through data.

[60] Plank et al. p. 4.
[61] Durand-Folco, Fourier and Tremblay-Pepin, "Redéfinir démocratiquement les besoins".

That being said, those are not the sole areas where democratic economic planning and social ecology intersect. In this last section, we thus explore a variety of issues pertaining to the meeting of both approaches. Recalling the criteria of regulation, limitation, and scope we briefly exposed in our second section, we are now better equipped to explore how socio-metabolic approaches can better inform and shape democratic economic planning models.

Starting with the regulation criterion, it is evident that the amount and variety of additional indicators social metabolism raises can, at first, sound impractical for planning models. Indeed, all three models mentioned in this paper are based on (phantom) prices systems: negotiated coordination relies on markets for all exchanges (but not for investments), phantom-prices act as the building blocks of the planning process in participatory economics and prices equivalent to labor value (but modified by supply and demand) are the core of Cockshott and Cottrell's model. Integrating approaches to social metabolism would then mean the retooling of planning models to account for additional indicators such as the mass of imported matter, the energy required to produce and consume goods and services or GHG emitted from these same practices and processes.

While this could mean an increase in importance for regulation relying first on quantitative data, here, the notion of provisioning systems brings new perspectives. As described above, regulation issues rely upon the foundational opposition between qualitative and quantitative data processing. What provisioning systems tell us instead is that both epistemological perspectives are interlinked in the dialectical process dedicated to symbolically identify, and physically satisfy societal needs. This is an obvious reality around which every democratic economic planning model has been conceived; a project that still struggles to culminate into concrete institutional forms. While the integration of new data made available by sociometabolic methods would hint at an exacerbation of the opposition between data-based and politically-based decision-making, we suggest that social metabolism could instead be the basis for a reconciliation of the two factors. Indeed, until humanity's computation power reaches proof that we inhabit a deterministic universe, it will remain unclear how a greater amount of empirical data can lead to more ethical decisions. Furthermore, a dialectical approach to regulation suggests that qualitative and quantitative data are both integral to provisioning systems and serve two distinct and complementary purposes, this would open up to interpretative processes through which scientists could derive more qualitative discourses from quantitative data (or help dedicated actors reach similar results).

In the provisioning systems theory we presented above, while the presence of a reflexive organ overseeing and shaping a society's internal processes is not explicitly rejected, its potential nature remains at the very least undefined. This is mostly due to a perspective in which society's basic state is seen as an innate ecological equilibrium from which derivative states are understood as imbalances to be corrected. Although a useful basis for ecological analyses, this perspective overlooks two facts. Firstly, we must note that societies' innate state, like any

dynamic system bound by the laws of thermodynamics, is a constant form of disequilibrium. Any strive for equilibrium must then be understood as the effort to maintain boundaries that depend in large part on humans' definitions and volition. Secondly, this perspective implies that a critical and reflexive approach in which humans shape their social and physical environment is central to any ecological perspective. This relies on humanity's capability for interpreting and defining what constitutes a proper ecological equilibrium. In this context, we can better understand how the proper administration of provisioning systems becomes democratic economic planning's primary objective. Sociometabolic analyses can serve to better shape the model's understanding of the current provisioning system to a degree wholly dependent on metabolic research's realization as a mediation between society-nature dialectics and as a vector for sociometabolic hermeneutics.

A planning model's principal issue would thus be the comprehensive synthesis of data so as to usefully integrate it into the planning process. Because of the complexity of raw metabolic data, the question remains if such multifactorial elements should, or even could, be directly integrated in an economic planning model's day-to-day operation. The reliance on an enormous quantity of qualitative and quantitative data to make every decision could indeed reveal impractical. On the other hand, its inclusion in institutions focusing on broader issues such as long-term and investment planning could be more easily feasible and result in better economic decisions, regulations and legislative actions. Here, societies' institutionalization capacities would thus prove extremely useful in order to properly structure metabolic forms of mediation. For example, workplaces could include agents whose role would be the problematisation of metabolic issues in production processes. Hence, the contribution of social-metabolic approach would manifest its deeper hermeneutical value, reframing the decision making process as a whole into a broader metabolic and political perspective.

This is where we rely on the limitation criterion. The introduction of an environmental perspective within democratic economic planning is, from its inception, a defense of specific limitations set partially outside of humans' control, but always only available through symbolic mediation and, therefore, human interpretative capacity. In this context, the argument for the structural integration of ecological factors in human society is rather different from the debates that might arise from the data produced by scientific institutions working on social metabolism. We suggest that this is because the problem at hand lies within the larger debate surrounding the polanyian re-embedding of the economy and the castoriadisian question of the self-limitation of democracy. Indeed, the integration of ecological limitations to humanity's action would be wholly dependent on a larger cultural transformation that would make possible the transmutation of our relation to limits. As Castoriadis showed studying ancient Athens[62], such integration of the idea of limit in a culture comes through the arts (like Greek tragedy) and the *paideia* emerging from the direct involvement of the people in democratic institutions able to limit themselves. The democratic planning of the economy can provide such a *paideia*, but only if its institutions can

[62] Castoriadis "The Greek polis and the creation of democracy"

reveal those limits, something that could be done through the integration of approaches to social metabolism.

While the conception of new institutions supplementing (shadow) prices by accounting for societal relations to nature might provide valuable technical data, there is reasonable doubt that these alone could provide deep and meaningful insights for society. The sole reliance on scientific institutions appointed to the empirical and communicative representation of social metabolism, while necessary to avoid the technocratic pitfalls - for example of a ministry such as the one proposed by Hahnel - would be insufficient to go beyond the simple generation of information. Thus, an institution able to act politically from that information would have to be included.

This undeniably leads to the larger debate surrounding how we value natural goods not yet appropriated by humans. While the complexity of the task is evident, the practicability of both MuSIASEM and MEFA as standalone and comprehensive models imply that such approaches could be functionally integrated to various planning models, thus offering an all-encompassing framework for getting a clear picture of our impact on the environment. Provisioning systems would also offer a good example of an external evaluation, a deeper perspective on the results of the democratic planning process. It would offer a clearer idea of the intricacies of the economy: the relationship between people's needs and the physical impacts of their satisfaction and an idea of what is superfluous and what is essential to its production. Even if informed by the best science available - creating as objective a representation of society and nature relations as possible - the valuation of nature and incidental economic decisions will depend on democratic consensus for the balance between autonomy and objective constraint to be reached within a more encompassing, innately limited economy.

This brings us to the scope criterion, which the context of a re-embedded and self-limiting democratic economy reframes regarding relations between actors and day-to-day problem solving. The integration of an institution responsible for establishing ecological limitations in the name of an ecological equilibrium would constrain and shape a society's metabolism. For example, a stricter definition of limits would call for a reduced range of actions while looser limits would open to a greater range. Furthermore, a specific culture built upon and through these limits would necessarily flourish, orienting actors' decisions. Thus, it could be inferred that in the longer-term, an endogenous generation of needs and preferences within this culture would help foster habits of self-limitation in democratic processes. Punctual variations in economic processes would still call for public consultation, at which point it is undeniable that actors would benefit from having access to the necessary information to make decisions in respect to the environment. The possibility of such a system would then rely upon the full integration of social metabolism by economic institutions, and upon the development of proper multifactorial indicators.

In which political institution the integration of social metabolism could be integrated to democratic economic planning? We believe that, on top of useful data, the socio-metabolic tools provide another level of planning to a democratized economy, raising its scope up to socio-metabolic planning[63]. This level is not only larger than Devine's investment plan, Hahnel's development plans and Cockshott and Cottrell's strategic planning, it also changes the definition and the process of long-term planning. In the three models, long-term planning processes could all be informed and, in some cases replaced, by socio-metabolic planning. Socio-metabolic planning's central issue would then be society's long-term need generation and satisfaction in the context of a fragile and limited ecological equilibrium. One of the tools to realize such planning would be a socio-metabolic representation of the economy in the workplace, as mentioned above.This would then require the capacity to produce a diversity of long term socio-metabolic plans, raising broad and recurrent debates about collective and individual needs[64]. As proposed by all models, this long-term socio-metabolic plan should be adopted by referendum - or through another large-scale public consultation process - and give the general objectives of society's relationship with the non-human world. This would then constrain annual planning by establishing sectors in which resources should be allocated in priority and the limits in which production and consumption should be achieved.

7. Conclusion

As we saw in this article, models of democratic economic planning and frameworks of social metabolism are doing two different things. On the one hand, the models are trying to propose institutions that would make possible the democratic control of the economy. On the other hand, the frameworks are building instruments assessing precisely the relationship between human and natural activity. Even if their goals are different, we sustain that those two efforts should be put together. That said, there is still work to be done before a thorough integration is reached. The three planning models we studied in this article account for moments to collectively evaluate broad objectives through public debate. Participatory economics now has long-term plans that include public debates and referendums. Negotiated coordination includes this reflexive process in the yearly planning process while computerized central planning does it when there are ecological consequences to human production. In this context, we propose that these long-term planning processes be informed by socio-metabolic planning based on the tools developed by sociometabolic research.

Democratic economic planning has always had one central goal: for its planning process to provide humans with the goods and services they wanted without ceding power to a central committee or to the automated movement of value accumulation. The integration of approaches to social metabolism into democratic planning is a step forward in attaining a self-conscious

[63] An idea that could realize the notion of metabolic self-limitation developed in Legault, "Planification démocratique : une proposition d'autolimitation métabolique".
[64] Durand-Folco, Fourier and Tremblay-Pepin, "Redéfinir démocratiquement les besoins".

economic process. The central question of economic planning is therefore two-pronged: how do we decide together what to consume and produce, and how can these decisions respect the equilibrium of the complex ecosystem we inhabit? In order to answer these questions and looking to inform long-term decision-making and day-to-day constraints on economic activities, we argue that the institutionalization of the capacity to represent societies' social metabolisms is a crucial step forward.

Considering how the many relevant economic actors would be mobilized in such endeavors, we can also see what democratic planning could bring to social metabolism. Indeed, the full transparency of democratic economy - as opposed to the secretive nature of the capitalist system - would facilitate data collecting. Furthermore, and more importantly, democratic planning offers social ecology, and ecological economics in general[65], a political economic framework in which the dialectical issues inherent to service-providing can be taken head-on. Democratic economic planning provides institutions in which actors can express needs, influence production techniques and determine shorter and longer term objectives. Therefore, we argue that the representation of social metabolism becomes part of a larger political process of transition towards more just and more ecological societies. Recent publications about approaches to social metabolism have discussed the role of such institutions. Now we suggest that the connections established in the present article could nourish the current reflection of this field.

[65] Akbulut and Adaman, “The Ecological Economics”.

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