ARTICLE IN PRESS

Ecological Economics xxx (xxxx) xxx

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

The international division of labor and embodied working time in trade for the US, the EU and China

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ARTICLE INFO

Keywords:
International Trade
Limits
Embodied Labor
Externalization
Sustainable Production and Consumption
Unequal Exchange

ABSTRACT

In sustainability analysis, human time is a crucial and overlooked societal limit. Some core countries overcome their time budgets and preserve their socio-economic structures by using energy and importing working time embodied in products and services. This paper analyses the roles of the United States, the European Union, and China in the international division of labor using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) framework. We calculated working time in production, consumption, and trade both in absolute and per capita terms, for the different economic subsectors in 2011. Energy Metabolic Rates (energy use per hour) and Economic Job Productivity (value-added per hour) complemented the analysis. Whereas the greatest share of the workforce in China was still in agriculture, the US and EU had it in the tertiary sectors by outsourcing large shares of agriculture, mining, and industry: they import about half of the labor time in their consumption. At the global level, the trade of embodied labor is a zero-sum game. This fact questions the long-term viability of the current pattern of development enjoyed by the EU and the US, as well as the possibility for emerging economies to complete a similar transition to a post-industrial economy.

1. Introduction

Biophysical limits have been an essential concept in the sustainability debates starting with Malthus (Malthus, 1798), the Limits to Growth (Meadows et al., 1972), and more recently the planetary boundaries (Rockström et al., 2009). Whereas external environmental limits have been thoroughly analyzed, internal societal limits have gone unnoticed. Human time is a crucial internal societal limit. Just as individuals have a 24 h budget of time a day to fulfill needs and duties, societies have a given budget of human time to sustain their metabolic activities. Social culture, institutions and technical structures at the upper level define the possible patterns of time use of individuals, what we call the social practice (Shove et al., 2012). Human time can be categorized in: physiological overhead, leisure, education, unpaid domestic work carried out by families (especially by women), and paid work (Giampietro et al., 2012). The latter is the main variable of study in this paper.

Paid work is an essential input to the economic sectors in market economies. The availability of paid work time depends broadly on demographic variables, i.e. the number of inhabitants and the relative size of the economically active population. Each society defines aspirations and regulations of who in this demographic structure is allowed or expected to participate in paid work, e.g., retirement and minimum working age, working women, and expectations on educational attainment. At another level, the total working hours per worker per year are determined by work regulations, namely holidays, working hours a day, safety conditions for different jobs, and parental leaves. Apart from changing this social organization, countries have followed two other strategies to adjust the profile of labor allocation in the economy given the budget of working time, which are those analyzed in this paper: increasing exosomatic energy use to boost labor productivity and outsourcing of activities.

Energy is a fundamental factor in the functioning of complex systems and shapes societal organization (Smil, 2008). The industrial revolution supposed a historical tipping point in the re-shaping of the economic structure of modern societies, associated with a fossil-fuel based metabolic regime. However, it was only during the 1950s that the use of cheap fossil fuels and other resources started to skyrocket. That Great Acceleration (Steffen et al., 2007) allowed a larger substitution of labor by mechanization that led to increasing societal complexity (Hall and

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https://doi.org/10.1016/j.ecolecon.2020.106909
Received 20 May 2020; Received in revised form 3 November 2020; Accepted 6 November 2020

Klitgaard, 2012; Tainter, 1988; White, 1943). Now we are able to get much more and a more diverse output relative to working time. At the same time, it has generated social acceleration and, paradoxically, time-pressure in the lives of individuals (Reisch, 2001; Rosa, 2013). More products and services are produced per hour of labor, but many more goods and services are required both in production and consumption.

Technical innovations such as international shipping and IT have shaped the modern world-system (Castells, 2010; George, 2013). Globalization has led to increasing geospatial separation of production and consumption, and, as a consequence, to an unprecedented displacement of impacts through international trade. Indeed, the fragmentation of production chains and specialization across countries obscure national and regional sustainability assessments, and hence compliance with the UN Sustainable Development Goals (SDGs) and the Paris Agreement. This problematic flags the need to build consumption-based indicators (Liu, 2015; Tukker et al., 2020). The literature on this topic with case studies on environmental variables is large and growing. Regarding the regions of study in this paper, there are diverse examples such as the environmental and resource footprints of the European Union (Tukker et al., 2016), carbon dioxide emissions embodied in foreign trade in China (Zhao et al., 2014), virtual water in trade in China (Chen et al., 2018), and a more recent one on the flow of embodied carbon in China, the EU and the United States (He and Hertwich, 2019).

Nevertheless, sustainability does not only require the feasibility in relation to biosphere constraints, but also the viability of the socio-technical organization and the desirability for its members (Giampietro et al., 2009; Saltelli and Giampietro, 2017). Just as with environmental impacts, outsourcing allows an increase in the consumption of working time without its local economic and social costs (reducing human time for care, education, retirement, etc.). Even though most of the consumption-based studies analyze environmental impacts and resource intensity, there is an increasing interest in this social perspective (Hubacek et al., 2016; Steinberger et al., 2012; Wiedmann and Lenzen, 2018). In the specific topic of paid work, there are studies on the British textile industry in the late 18th and early 19th centuries (Hornborg, 2006), labor and wage footprints (Alsamawi et al., 2014), labor footprints in the EU (Simas et al., 2015), "bad labor" footprints (Simas et al., 2014), and the study of diverse embodied variables in trade including labor in 2015 (Dorninger et al., 2021).

While these studies have pinpointed the extent of outsourcing of such environmental and social impacts through pressure indicators, it is often overlooked that the externalization of energy and labor-intensive activities underlies the socio-economic organization of society. To assess that, we analyzed both the internal working structures and trade relationship with an aggregated manageable number of sectors and countries. Studies that include all countries usually end up focusing on those with the most exceptional patterns. We instead choose deliberately the US, the EU, and China, which are the largest importers and exporters worldwide in terms of the value of trade (Eurostat, 2018). These regions play a major role in the world system in other diverse dimensions (see Section 3.1). Moreover, their political and economic influence has sparked conflict in the last years precisely due to trade (Emmott and Barkin, 2018; Paletta and Swanson, 2017; Tankersley and Bradsher, 2018).

In this paper, we assess the labor embodied in production and trade between China, the EU27, the US and the rest of the world in 2011, within the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) framework (Giampietro et al., 2013; Giampietro and Sorman, 2012) at the level of both whole regions and economic sub-sectors. Moreover, we relate time with secondary energy use in order to better understand the nexus of social and environmental constraints. We provide new insights into the effects of trade on their metabolic patterns embedded in the worldwide economy. We explore human time as a societal limit, its role in production and consumption, and the dependencies that arise from trade. In this way, we can study how externalization of specific economic sectors allows some countries to concentrate its budget of paid work to higher-value services and other services that increase the wellbeing of their population. This paper complements the analysis of the metabolic patterns of China and the EU in (Velasco-Fernández et al., 2020b).

2. Materials and methods

2.1. MuSIASEM and the fund-flow scheme

MuSIASEM is a 'meta' accounting framework purposely developed for studying the complex metabolic pattern of social-ecological systems at different hierarchical levels, scales and dimensions of analysis (economic, social, demographic, ecological, etc.) (Giampietro et al., 2013; Giampietro and Sorman, 2012). It is based on the fund-flow scheme of Georgescu-Roegen (1971). Flows are either consumed or produced during the time of analysis (e.g., value added, energy throughput, water, greenhouse gas emissions), whereas funds can be considered to remain the same and define the size of the system. The latter sustain the activities of the society and must be reproduced: human activity (Giampietro et al., 2012), land use (Serrano-Tovar and Giampietro, 2014) and power capacity (Diaz-Maurin, 2016). The existence of metabolized flows in MuSIASEM is always analyzed in relation to the fund elements metabolizing them (Velasco-Fernández et al., 2020a). This coupling of funds and flows allows the analysis of the implications of the size of the metabolic pattern. An analysis especially important in a globalized economy where economies are more and more open, indirectly using funds from other countries. This approach provides an alternative perspective to the common use of flow-flow indicators in sustainability analysis, such as energy intensity (€/MJ), which does not give enough information about the relevant factors determining the metabolic pattern (Fiorito, 2013; Velasco-Fernández et al., 2018).

Analyzed in a given year, the total global amount of funds is by definition constant. In the case of human activity, it is measured in hours and calculated multiplying the population by 365 days a year and 24 h a day. This amount of human time must generate closure for all activities carried out in the society in that year. The use of funds, if maintained properly, does not exclude their future use. In contrast, stocks (mineral or fossil fuel reserves) are defined by its depletion as they are exploited, and their current use excludes use for future generations. This means that there is a clear zero-sum game in the considered timeframe in terms of embodied funds (human time) in traded goods and services, where some countries can expand their existing funds at the expenses of others. When considering individual economies, we can find large differences in the size and characteristics of the funds used for producing or consuming traded commodities and large differences in the flow/fund variables and other qualitative characteristics, which are key drivers of unequal exchange: labor productivity, wages, workers' rights and conditions, etc. The limitations of the budget of time can also be avoided by increasing the productivity of funds, using more energy and other resources. Considering more variables and sectors (energy, materials, infrastructure, etc.), we could see that the definition of the patterns of human activity is further defined by the mutual information and impredicativity of the whole system in what is called the Sudoku effect (Giampietro and Bukkens, 2015).

This means that a complex combination of structures, requirements, decisions and trends defines (and at the same time is defined by) the amount of funds used for each function (e.g. number of workers in agriculture, area devoted to crops) and left unmanaged (e.g. wild forests). Changes in the profile of human activity depend thus on several factors: demographic structure, cultural characteristics determining the current social practices, infrastructure requirements of time for its functioning, economic structure, and power within the global market. By adopting an articulated representation of the metabolic pattern of countries, it is possible to study the implications of the characteristics of human time allocation across different levels of analysis (individuals, households, countries, the world economy). As we have already said, we are focusing on working time in the market economy, linking the country with the global level. This is only a part of the whole set of relations that exist in the metabolic pattern of social-ecological systems, that we will consider but not fully analyze.

In this application of MuSIASEM, we analyze the following variables:

- Human Activity (HA, in h per year), fund: working time spent in market activities. Labor time is considered a fund in the yearly timeframe, although it also fluctuates at larger timeframes due to demographic, economic, and social changes. Only paid work in the market economy is accounted for in this paper for all variables. Despite the indispensability of unpaid domestic work for social reproduction (Carrasco Bengoa, 1988; Hoskyns and Rai, 2007), systematic data for all countries is still lacking and wage labor statistics are still central. There could be as well indirect inputs (not accounted here) in the form of activities of social reproduction in the exporting societies. Further work would include a thorough analysis of the use of time in all sectors of society.
- Economic Job Productivity (EJP, in \$/h), flow-fund ratio: Value added generated per hour of work.
- Energy Metabolic Rate (EMR, in MJ/h), flow-fund ratio: throughput of energy carriers per hour of work in the end uses, classified in electricity or thermal energy. The different characteristics of these kinds of energy must be taken into account (Giampietro and Sorman, 2012). The value of EMR_i is considered in MuSIASEM a proxy of the capitalization of the economy (Giampietro et al., 2012). Different economic activities have different EMRs by its own nature, such as metal forging and food industry. Moreover, the same activity can have different EMRs depending on the way it is carried out, for example, traditional manual and industrialized monoculture agriculture.

It is important to note that in order to study the factors determining the profile of allocation of human time associated with the profile of energy uses we have to focus on the relation between hours of work, the characteristics of power capacity, and the tasks to be achieved in the working activity. Within the metabolic pattern, we can divide energy transformations in two categories: (1) those referring to the catabolic phase – in which favorable gradients found in the environment (the primary energy sources whose existence does not depend on human agency) are destroyed in the energy system in order to generate secondary energy useful for the final uses of energy in society; and (2) those referring to the anabolic phase – in which secondary inputs are used by combining labor and technology to build structural elements and to express functional tasks. In our analysis of the use of the human time we are focusing only on the anabolic part. In order to analyze the time required by a worker using a tool powered by electricity, it does not matter whether the input of electricity has been produced by a coal or by a hydroelectric plant. Therefore, the Energy Metabolic Rate that describes qualitatively the given activity must be calculated in relation to the use of secondary energy. For this reason, we consider only the consumption of secondary energy flows outside the energy sector, namely the energy carriers consumed in the various paid work activities. That is, in this paper we do not aim to calculate the energy footprint of consumption, but how human activity is a key limiting factor in the reproduction of socio-ecological systems. This entails identifying the economic transformations depending on the availability of paid work that regulates the use of secondary energy in the economy. Therefore, this study does not include the quantities of primary energy that are taking place in the energy sector, the catabolic part, for example the coal spent in producing electricity. It also neglects the concomitant effects on GHG emissions or the depletion of fossil fuel stocks. Assessments of these quantities are certainly relevant for studying other aspects of sustainability and can be calculated using a different accounting scheme to answer a different research question. As a matter of fact, MuSIASEM has been already used for some of these different types of analysis, including exosomatic energy systems in Ripa et al. (2021), Parra et al. (2020) and Diaz-Maurin and Giampietro (2013), and endosomatic energy systems: Cadillo-Benalcazar et al. (2020) and Renner et al. (2020).

2.2. Data and data sources

The Trade in Value Added database (TiVA, DVA_{ikj}) was the main source of data (OECD, 2019). It is a set of indicators based on the inter-country input-output OECD tables. It reveals how the value of final demand goods and services consumed within a country is an accumulation of value generated by many industries in many countries in global production networks : *Value added embodied in final demand*. Value Added data captures better than Trade the role of countries, avoiding the double counting implicit in gross flows of trade (Koopman et al., 2014). Countries do not produce from cradle to gate, they are contributors to intertwined global processes where materials and intermediate products cross borders multiple times before getting to their final consumers (Sturgeon, 2001). Clear examples of this international distribution of production are the global value chains of electronic products (De Backer and Miroudot, 2013) and Barbie dolls (Tempest, 1996). Moreover, some products do not even undergo any physical transformation in countries which only are intermediate ports due to lower tariffs or to avoid sanctions, namely re-export or entrepot trade.

Countries play different economic, political, and productive roles in global production networks. Even though the final analysis included two supra-national regions of analysis (the EU and Rest of the World) and an aggregated classification of sectors, the results were calculated with the most disaggregated values available by industries (34) and countries/regions (45). This classification could have influenced the results, such as the inclusion in the same category of Wholesale and retail trade. The classification of economic activities hides differences in activities which belong to the same category but have completely different resource uses, and even the same activity can be performed differently. For example, for Pulp and Paper, Finland has a very energy-intensive industry devoted to pulp, whereas Portugal has a less capitalized pulp sector, and in Italy, the activity of the sector is oriented to final paper products manufacturing (Velasco-Fernández et al., 2019). The classification of economic sectors was finally further aggregated in 8 categories for the analysis in the figures (reference table in the Supplementary Material, SM Table 3): Agriculture, Mining, Industry, Utilities, Construction, Transport and telecom, Services, and Finance and offices. The regions of analysis are China, the United States, and the European Union (the 27 Member States in 2011) and are complemented by the Rest of the World.

The data of Human Activity by country and industry (HA_{ik}) was taken from the Exiobase version 3.3 database (Stadler et al., 2018; Tukker et al., 2013; Wood et al., 2015) summing the categories of Employment hours by skill and sex in the factor inputs table.

Energy Throughput (referring to secondary energy or energy carriers) by country and industry (ET_{ik}, electricity or thermal) was taken as well from the Exiobase version 3.3 database (Stadler et al., 2018; Tukker et al., 2013; Wood et al., 2015) and the materials table, more specifically the category Electricity, and the sum of categories Emission Relevant Energy Carrier for thermal. As noted earlier, we included only energy carriers to end uses outside the energy sector, excluding primary energy or carriers used to generate other types of carriers, e.g. natural gas to produce electricity in cogeneration power plants. For this reason, the economic sector Utilities (C40T41 – Electricity, gas, and water supply) is not included in the analysis of Energy Metabolic Rates. We differentiate between thermal and electricity, acknowledging their different natures and paths within the energy system (Giampietro and Sorman, 2012).

To get the embodied time (HA_{ikj}), the Economic Job Productivity of each country-industry (EJP_{ik}) was multiplied to the trade in value added (DVA_{ikj}) generated by the consumption of each region. An important hypothesis laying down the calculation is that each sold monetary unit had the same economical and technical characteristics no matter the country of final demand. Nevertheless, it is known that companies that export have different characteristics than those who produce for domestic consumption, at least in the case of China (Upward et al., 2013).

$$EJP_{ik} = \frac{HA_{ik}}{\sum_{j} DVA_{ikj}}$$

$$HA_{ikj} = DVA_{ikj} \cdot EJP_{ik}$$

i: country of production.
k: industry of production.
j: region of consumption (China, EU27, US or Rest of the world).

In order to get the Energy Metabolic Rate of each country-industry (EMR_{ik}), we divided Energy throughput (ET_{ik}) by its working time. The consumption-based EJP and EMRs include the value added, labor, and energy carriers in domestic production that is consumed locally (not exported) and those embodied in imports.

$$EMR_{ik} = \frac{ET_{ik}}{HA_{ik}}$$

.
i: country of production.
k: industry of production.
.

3. Results and discussion

3.1. *The regions in the global picture*

In Fig. 1, we can see the relative share of the regions of study regarding different variables in a production-based perspective: total population, human activity, value added, electricity and thermal energy in paid work. Even though the sum of the US, the EU, and China represented only 31% of the population and paid work time, they generated more than half of the value added and consumed about half of the electricity, and thermal energy of the world in paid work. What is more, the US' and the EU's shares are more disproportionate. Together, they generated 45% of the value added worldwide and accounted for 32% of electricity and 27% of thermal energy consumption in paid work, despite their relatively small total population size (4% and 7% respectively) and human activity invested in paid work (4% and 6% resp.).

Rest of the World (ROW) was the largest region in terms of inhabitants and working time and includes a large number of countries very diverse in their economic development. Because of this heterogeneity, its average values of consumption carry little meaning. The EU and US comprised 70% of the population in "more developed regions" in 2010 according to the UN (United Nations. Department of Economic and Social Affairs. Population Division, 2019). This category includes all countries in Europe and Northern America, plus Australia, New Zealand, and Japan. Therefore, that 30% left in ROW may follow a pattern similar to that of the US and EU. The exporting net situation of ROW shown in the results is very likely to be exacerbated in less developed regions.

3.1.1. *International division of labor*

Fig. 2 shows the local work structure of the regions of analysis and the global picture. Each country participates differently in the international division of labor. Most working time was still on Agriculture, forestry, and fishing both for Rest of the World (33%) and China (44%), whereas it represented only a small share in the EU (6%) and the US (2%). However, working time itself is not a good proxy of production, and even more in agriculture, where very diverse production types coexist worldwide, characterized by their Energy Metabolic Rate (energy per hour of labor). Most of these workers in China are low-tech peasants, whereas animal farming and the use of machinery for crop production define agriculture in the EU and the US. The large agricultural production of the US is vital for its food security but at the same time minor in value-added terms. It requires solely a tiny amount of workforce (about 2%) but it is boosted by power capacity and other inputs, for example, energy, pesticides, fertilizers, and water.

Transport and Finance and offices manage material and monetary flows worldwide. Transport and logistics are essential structures to organize in time and space the increasingly complex global production networks. The US (22%) and the EU (15%) had especially large shares in Finance and offices compared to the other regions and the global level (10%).

Some activities are very connected to geographical locations. Soil and climate determine agriculture, whereas Mining is even more limited to the specific locations of profitable ore stocks (plus social acceptance and less strict environmental regulation). In another way, most of the subsectors in Services are linked to the place where users live, such as education, healthcare, retail, or government. Thereby, these latter activities are not outsourceable. This is the category where most people worked at a global level (36%) but represented even about half of the working time in the EU and the US.

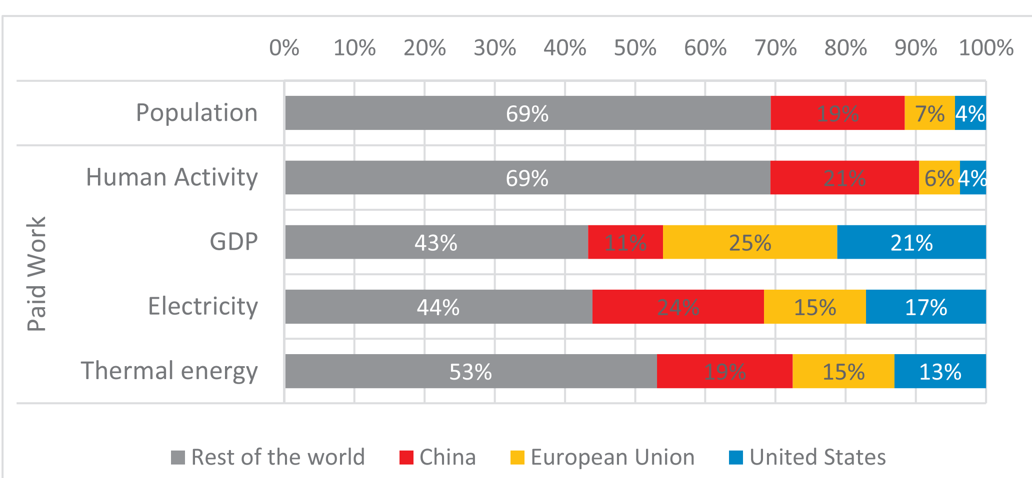

Fig. 1. Relative share at world level of inhabitants, value added (VA), and human activity (working time in h) and energy (electricity, and thermal energy) invested in paid work for China, the EU, the US and the rest of the world (ROW) in 2011.

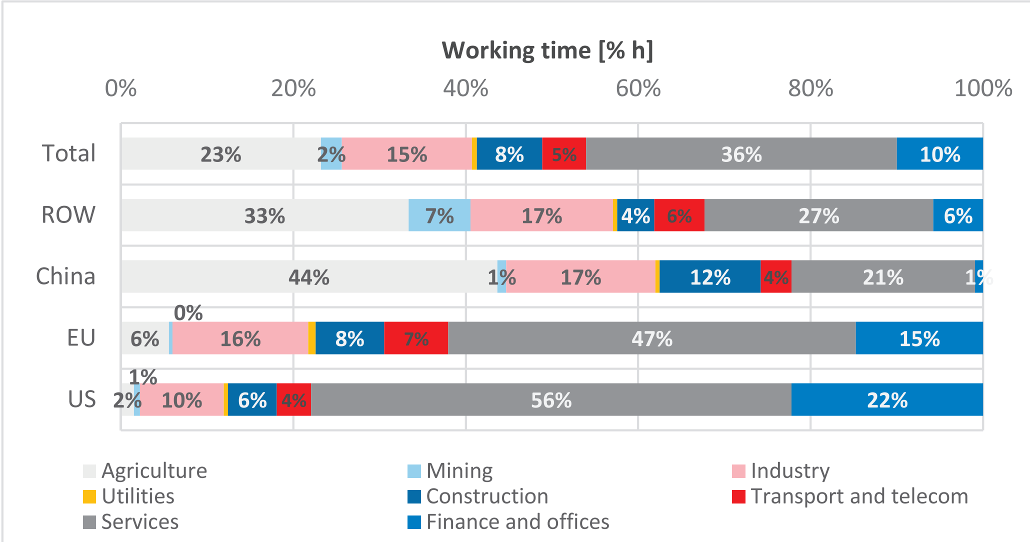

Fig. 2. Shares of working time (%h) per sector for all regions and the world (total) in 2011.

3.2. Production, consumption, and trade

3.2.1. Regions

Fig. 3 shows the total working time in production and trade for each region of analysis. Positive values and bars in darker colors refer to Consumption of the country (imports and a part of the domestic production), and negative numbers to Exports (the part of exported domestic production). The colors of the bars define the country of production in the case of the positive values, and the country receiving exports in negative: grey for the rest of the world, red for China, yellow for the EU, and blue for the US.

Here we can see that both the US and the EU were net importers of working time and rely more on work performed outside of their boundaries. 50% and 54% respectively of their consumption was satisfied with embodied work in imports. More specifically, 10,5% and 6,8% of the embodied work in their consumption was Chinese. In contrast, China showed larger self-sufficiency. 91% of its consumption was local and the EU's and the US' imports contributed marginally (0,4%). It even had an almost balanced trade with the Rest of the world. We can relate these results to those in Alsamawi et al. (2014), where they classify countries as masters and servants. Masters import cheaper labor from servants. Both the US and the EU are masters, whereas China is an intermediary country, neither master nor servant. Similarly, the world-system theory of Wallerstein (2011) classifies the US and the EU as core regions and China as semiperipheral.

Human activity in exports ranged from 10% to 15% of the local production for all regions of study. What it is a large input of time per capita for the EU and the US is a relatively low export for the rest of the world. This means that it is relevant that core countries such as the EU and the US have smaller populations than that of the importing peripheral region, both China and most of the rest of the world. However, the rest of the world comprises a heterogeneous variety of countries. Some of them are developed countries likely to have the same net importing characteristics as the US and EU, whereas less developed countries would export a larger share of the work embodied in their local production. Existent literature suggests as well this situation (Alsamawi et al., 2014; Simas et al., 2015, 2014). A further, more detailed analysis would be needed to discern differences in the countries in the rest of the world.

With the values per capita, we can analyze the consumption of citizens, i.e., the number of hours that are required to sustain the consumption of an average citizen in each of the regions, shown in Fig. 4. In this perspective, we can see the US and EU had larger embodied working time in consumption than China. Moreover, China was the largest exporter per capita, and it exported more than it imported. Local working time per capita in the same China was larger than those of the US and the EU. However, imports made that the larger consumer of working time was the US' average citizen, with 1430 h/(cap·yr), which was about twice the paid work invested in the local economy: 783 h/(cap·yr). Afterward, there was the EU average citizen with 1238 h/

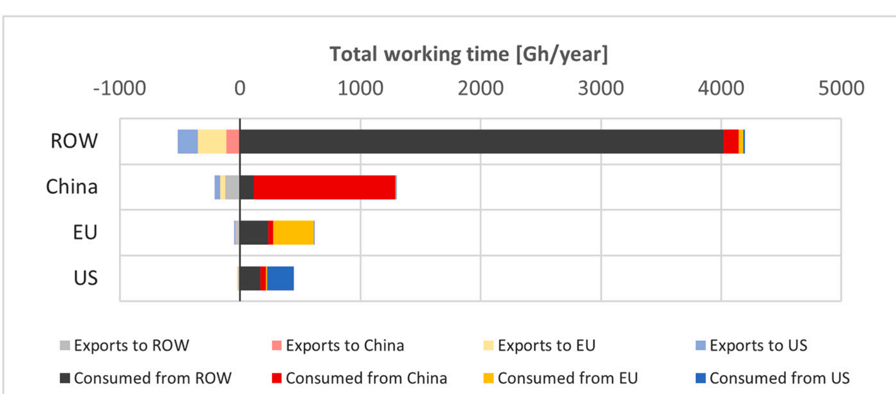

Fig. 3. Total working time (Gh/year) in exports, production, and imports by region in 2011.

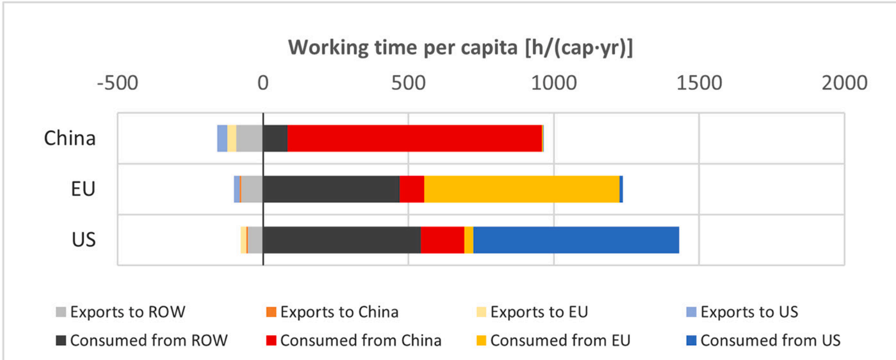

Fig. 4. Working time per capita (h/(cap·yr)) in exports, production, and imports by region in 2011.

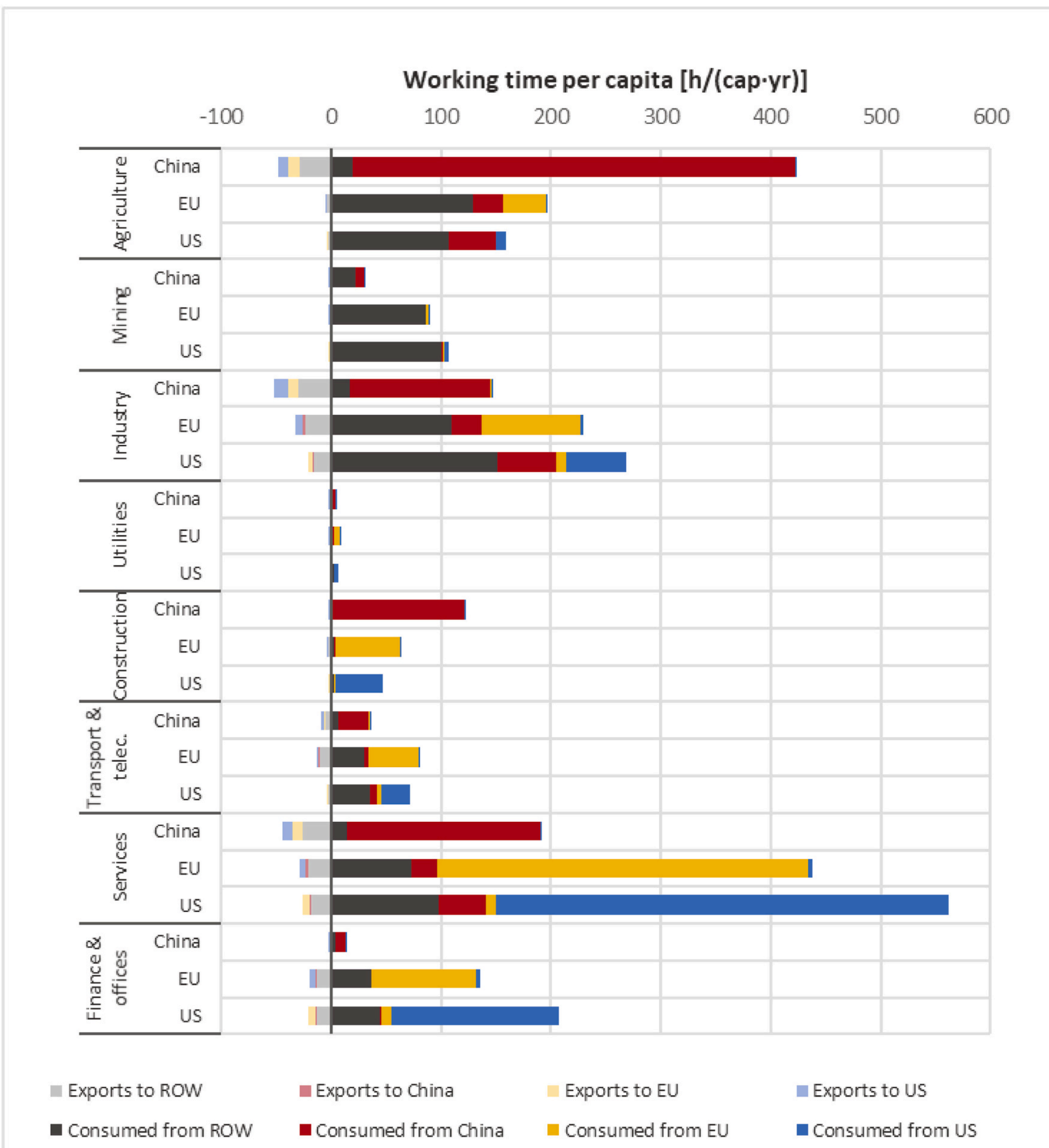

Fig. 5. Working time per capita (HA, in h/(cap·yr)) in exports, production and imports by region and sector in 2011.

(cap·yr) (760 locally invested) and the Chinese with 963 h/(cap·yr) (1033 locally invested). Compared with China and the Rest of the World, the EU and the US relied more on embodied working time both in relative (per capita) and absolute terms (total hours), despite its smaller population. These results add to the literature on environmental impacts and material consumption-based indicators: what means a better life for the EU and the US is a cost for others (Brand and Wissen, 2018).

3.2.2. Economic sectors

Besides the differences in population, the economic sectors also play different roles. Fig. 5 shows the embodied labor time per capita for each economic sub-sector and region. At first sight, there was large self-sufficiency in the sectors Utilities and Construction. Construction requirement of labor per capita was way higher for China, which shows the state of urbanization and building of infrastructure.

In all the other categories, the Rest of the world had significant participation, which becomes especially relevant in Mining. The almost complete externalization of Mining and quarrying in the EU might be a consequence of resource scarcity, Not In My Backyard (NIMBY) opposition to mining projects, and the existence of the global commodities market. Working time is not a direct proxy of the production since a lower amount of working hours can be compensated by a larger use of energy and machinery, here identified by high Energy Metabolic Rates (EMR, see supplementary material SM Figure 2 and SM Figure 3). In the case of the EU and the US, EMR for Mining are the largest or second-largest both for electricity and thermal energy. The associated large Economic Job Productivities (SM Figure 1) of these sectors might explain their generation of significant environmental impacts.

In general, both the US and the EU relied strongly on work performed outside its borders in material extraction and transformation (Agriculture and fishing, Industry, and especially Mining and quarrying). For these categories, embodied time in imports represented 75% (EU) and 87% (US) of consumption, whereas for China it was only 10% (Fig. 5).

With respect to Industry, although imports of embodied time from China to the EU and the US were significant (12% and 20%), the Rest of the world was their largest supplier (48% and 56%). China showed larger self-sufficiency and larger exports per capita. China is thus believed to be the factory of the world. Nevertheless, in many cases, it imports intermediate products, and it is only the final assembler of goods: a part of the Global Production Networks. *Made–in-China* products have many other manufacturing locations where vital intermediate processes are performed.

The difference in Energy Metabolic Rates in industry reflects not only larger mechanization but also the fact that different subsectors are located in different countries. Industries in the EU and the US had higher production-based EMR and Economic Job Productivities than China. That means they are very technology-based, niche and have limited but international demand, such as pharmaceutical, aerospace, IT, and robotics. This is why a large share of their production is exported. On the other hand, the Chinese government has developed the Made in China 2025 strategic plan, which aims to upgrade technologically the country's manufacturing. Its textile industry is a clear example of a labor-intensive industry that has started to be relocated to third countries like Bangladesh or Sri Lanka. It is no surprise that this transformation of the Chinese industry is giving rise to increasing competition and international tensions (Paletta and Swanson, 2017; Tankersley and Bradsher, 2018).

A paradigmatic example is the relationship between the US' and China's Industries. The average US consumption per capita of embodied time from the local industry and imported from China was approximately the same, about 55 h/(cap·yr). Whereas the Economic Job Productivity of the 55 h/(cap·yr) of Chinese industry was only 10 $/h, the EJP of the US counterpart was 7.5 larger (75 $/h). Of those 55 h imported hours from China, the larger shares were in labor-intensive subsectors with even lower economic productivity. 18 h were in the subsector Computer, Electronic and optical equipment with an EJP of 5.1 $/h, and 9.8 h in Textiles, textile products, leather, and footwear with an EJP of 5.7 $/h.

The US and the EU's workforces were devoted mainly to Services and Finance and offices (78% and 62% of the working time respectively). Despite their smaller overall workforces, they consumed about twice of China's labor per capita in Services. The difference widens in the case of the Finance and office work sector. The EU and the US are service-centered societies and rely on the work performed elsewhere for their material consumption.

The relatively low EMRs in Services and Finance and offices show that what could be defined as a more sustainable society is, in fact, only based on value-intensive services. That thus depends on the overseas manufacture for their material needs, externalizing their environmental impacts and work requirements. Substituting work in the industry, characterized by high EMRs, by work in services, with low EMRs, ends up with a decrease in direct energy consumption that could be understood as energy efficiency improvements with a production-based approach.

Services have become central through a process of de-industrialization of specific industries in the US and EU. This led to environmental quality improvement, but also the loss of local well-payed jobs and increasing unemployment (Smil, 2015). In the global economy, transnational companies take advantage of lower wages and less strict regulations in poorer countries. However, these transnational companies often maintain headquarters in the home country and their subsequently higher value added activities in Finance and offices that support production and consumption (research, design, marketing, logistics, retail), the so-called smile curve (Del Prete and Rungi, 2017). Some scholars point out that the control of service activities only represents an overestimation of the role of developed countries, and the capture by transnational corporations of value generated in production in the developing south (Ali-Yrkkö et al., 2011; Reinert, 2011; Roy, 2017; Smith, 2012).

A consequence is an increase in exports of Finance and offices, which can be seen in the large amounts of labor exported by the EU and the US. However, these exports are fluid and not restricted to specific infrastructure. Therefore, office work is susceptible to be as well relocated to developing countries such as China as their younger generations get higher education (Chang et al., 2013; Smil, 2015).

On the other hand, there are other Services, which in many cases are labor-intensive and define the level of wellbeing of the population. Within this category, there are structural sectors such as wholesale, public administration, and defense, but also many services directly connected to social welfare that are non-outsourceable: education, healthcare, hotels and restaurants, retail, and social work. In this case, both local and consumed working time were greater for the US and the EU than China (local allocation: 411, 332, and 180 h/(cap·yr) respectively).

Some activities can be carried out both within and out of paid work. Even though we would need time use statistics on unpaid work to perform a thorough analysis (Hoskyns and Rai, 2007), we introduce two examples: children's care and cooking. Local time per capita in the subsector Health and social work were 98 h/(cap·yr) for the US, and 10 h/(cap·yr) for China, with lower availability of doctors and an approach to dependency care based on unpaid work. Retired Chinese grandmothers take care of children to a great extent while young mothers are working. Women have a low retirement age in China, 50 or 55 years old depending on the type of job. Its planned raise due to the aging population will pose a challenge to this care system (Yu et al., 2018). As another example, a large share of the time in services in China came from Hotels and restaurants (70 h/(cap·yr) compared with 32 in the EU or 50 in the US). This working activity decreases time in domestic work for food acquisition and preparation allowing longer workdays for the other workers.

Finally, some services related to entertainment do not only need large amounts of labor but also the availability of leisure time (Zipf, 1941). Hence, it makes sense that the US and the EU, which have lower working time per worker and a larger share of nonworking population, have more services as well.

4. What about an international reallocation of working time?

In this section we propose a scenario of reallocation of working time in the global economy to flag the relevance that this issue should have in sustainability discussions. As we have seen, the societal limits associated with the budget of human time in the US and the EU have been overshoot by means of trade and capitalization. Citizens of these countries enjoy a living standard that would require much more work than what they are allocating in their market economy. This expansion of consumption by core countries has been obtained at the expenses of peripheral and semiperipheral countries, such as China, which are competing to achieve that central role and become working time importers, increasing pressure on the global time budget.

This large net import of embodied work in core countries challenges proposals like working less for sustainability (Antal, 2018; Kallis, 2013). Instead, it makes us rethink developed societies to turn upside down the international division of labor that leads to an unequal exchange (Wallerstein, 2007). This is a political question that needs a broad debate on the interconnected social practices and environmental pressures generated by the relation between core, peripheral and semiperipheral countries in the globalized economy. We pose a question to make a first rough exploration: what if core countries agree on reinternalizing most of the economic activities they are outsourcing at the moment?

Table 1 presents a summary of the hours and number of workers in production and trade, and population for China, the EU, and the US. It includes a rough assessment of how many equivalent workers would be needed to fulfill the current levels of consumption with the existent hours per worker. In 2011, these hours per worker were significantly lower for the US and the EU (1718 and 1759 h/(worker·yr)). The extra virtual workers of the EU and the US would be 136 M and 117 M (against 216 M and 142 M existent workers in 2011), whereas China would gain 42 M virtual workers that are now working for imports. Clearly, this would not be a viable scenario for the EU or the US. 83% of the population of the US in 2011 should work to cover all the work that is consuming. Instead, assuming that workers would accept Chinese working times (2222 h/(worker·yr) – an increase of about 30% of current yearly workload), the EU and the US would require "only" 58 M and 62 M extra workers respectively, which couldn't be tackled with current unemployed people alone. A reinternalization would negatively affect their material standard of living and jeopardize their existent decarbonization plans and goals.

Unwanted societal changes could include later retirement age, less education before entering the workforce, an increase of the workload in paid work, a reduction of the work force in the service sector to increase it in primary and secondary sectors. Within a given societal budget of human time, an enlargement of working time in a category necessarily implies decreasing that of others. For example, increasing the paid work will reduce unpaid work or leisure work, and thereby will heavily affect the current pattern of social practices.

In terms of sectors, the imported jobs for the EU and the US are mainly in primary and secondary sectors that were dismantled via deindustrialization processes. Some existent service jobs may be worthless to society (Graeber, 2019) and easy to eliminate, others could be substituted or complemented by technology. However, a significant decrease of labor-intensive services to people (e.g., education and healthcare) affecting wellbeing levels could be necessary in order to decrease material dependency. An international reallocation of working time is not a mere re-allocation of hours in an excel spreadsheet. Jobs are linked to out-of-work practices, abilities, cultural values, knowledge, infrastructures, and natural resources.

This shift would as well require rebuilding industrial infrastructure. However, the current high level of energy use is generating problems in both stocks (fossil fuels, materials for renewables), and sinks (GHG emissions, pollutants). A transition to a lower energy consumption would force a decrease in the Energy Metabolic Rates of activities. This would require larger amounts of labor to produce the same output, something that would further increase the pressure on the human time budget. We can only conclude that current socio-technical organization should be radically reconsidered, prioritizing those activities that are essential.

5. Conclusions

The global budget of human time is a societal limit to consider in the sustainability discussion. Global working time allocation among countries is a zero-sum game. However, regional time budgets can be eased by means of technical capital or avoided altogether by externalizing some of the activities required by society. Core countries have a favorable embodied labor trade balance at the expense of peripheral countries, similar to other well-known variables such as GHG emissions, water, or energy. This additional time consists mostly of cheap labor from material transformation sectors (primary and secondary).

The size of the importing core countries plays a key role. Only a small part of the world population can enjoy a large surplus of embodied working time without generating too large social and political tensions somewhere else. The global budget of work explains the struggle for hegemony by the emergence of developing countries such as China. International trade and globalization have given rise to global production networks, which assign specific functions to each region and build a worldwide division of labor. Countries compete for the higher value-added economic structure that allows a greater consumption, more labor-intensive services to people, and shorter working hours.

In this paper, we calculated the embodied quantities of labor time in production, consumption, and trade for China, EU27, and the US in 2011 and their relation to final energy use and generation of value added. The fund-flow perspective and the MuSIASEM framework allowed us to analyze the metabolic pattern of the regions, their economic sectors, and the dependencies that arise from trade.

In descending order, the consumption of embodied working time for the average citizen was the US, the EU, and China. What is more, the products and services that the US and the EU consumed required almost half of the working time available to these economies invested out of their boundaries. Trade and intense capitalization allowed them to work fewer hours per worker, to have a smaller fraction of employed

Table 1
Summary table of hours, population, workers and required equivalent local workers to fulfill consumption for China, the EU and the US. Population data from (United Nations. Department of Economic and Social Affairs. Population Division, 2019). Percentages of workers are in relation to the total population in 2011.

	Working hours per year					Number of people [10^6]					
	Total [10^9h]		Per capita [h/cap]		hours per worker [h/worker]	Total population	Workers				
	Production	Consumption	Production	Consumption			Total		Required for consumption		Difference
China	1393	1299	1033	963	2.222	1348	627	47%	585	43%	−42
EU	380	619	760	1238	1.759	500	216	43%	352	70%	+136
US	244	446	783	1430	1.718	311	142	46%	259	83%	+117

population and to concentrate the paid work on high value-added sectors and services to people. Imports for the EU and the US embodied a great number of hours especially in agriculture, mining, and industry. Therefore, their working time surplus is dependent on vital processes happening abroad.

China's economic structure showed a different pattern, and agricultural activities still had the greatest share of workers. In general, China was more self-sufficient but still required imports from mining, an activity related to the geological existence of stocks. Embodied working time in imports from the US and the EU was not substantial.

These differences raise a political question: a rather small part of the world population is relying on labor from the rest of the world. Alongside this, there are also known ecologically unequal exchanges in relation to consumption of materials and generation of environmental impacts. Finally, the dependence of the EU and the US on essential production processes outside their boundaries is posing a risk in a world with growing tension due to the development and competition of emerging countries like China, India, or Brazil. The outsourced economic activities in the EU and the US could not be internalized within their current socio-economic structure and societal expectations of working time. This internalization would increase of energy consumption in material transformation activities, moving them away from their regional sustainability goals.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was funded by the European Union's Horizon 2020 research and innovation programme under grant agreements No. 649342 (EUFORIE) and No. 689669 (MAGIC). Laura Pérez-Sánchez gratefully acknowledges financial support of the Catalan administration/AGAUR (Grant number: 2019FI_B01317). The authors also acknowledge financial support by the government of Catalonia (AGAUR), through the support for research groups (2017-SGR-230), and the Spanish Ministry of Science, Innovation and Universities, through the "María de Maeztu" program for Units of Excellence (CEX2019-000940-M). This work reflects only the authors' view; the funding agencies cannot be held responsible for any use that may be made of the information it contains.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2020.106909.

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