Journal of Cleaner Production 380 (2022) 134836

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

The circular economy and longer product lifetime: Framing the effects on working time and waste

Tommaso Luzzati [a,b,*], Tiziano Distefano [c], Samuele Ialenti [d], Valeria Andreoni [e]

[a] Dipartimento di Economia e Management, Università di Pisa, Via Cosimo Ridolfi 10, I-56124, Pisa, Italy
[b] Leonardo-IRTA, Istituto di Ricerca sul Territorio e l'Ambiente Via Pasquale Paoli, 15, I-56126 Pisa, Italy
[c] Dipartimento di Scienze per l'Economia e l'Impresa (DISEI), Università degli Studi di Firenze, Via delle Pandette, 32, I-50127 Firenze, Italy
[d] Dipartimento di Economia e Scienze Sociali, Università di Torino, Corso Unione Sovietica, 218 bis, 10134, Torino, Italy
[e] Management School, University of Liverpool, Chatham Street, Liverpool, L69 7ZH, UK

ARTICLE INFO

Handling Editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Working time
Material consumption
Waste reduction
Circular economy
Product lifetime

ABSTRACT

An important goal of circular economy strategies is the extension of product lifetimes, under the assumption that this will deliver reductions in materials, energy use and waste. More broadly, longer lifetimes might counter the "broken windows fallacy" on which much of economic growth is based. The aim of this paper is to elaborate on this assumption rather than take it for granted. What are the systemic effects of policies aimed at saving materials? Who will benefit from them? To answer these research questions, we start connecting two issues that are often handled separately, despite being closely interlinked, namely (i) working time reduction and (ii) (over) production and waste generation. Trends in work indicators and material consumption in the EU15 countries confirm that higher material efficiency has not delivered the hoped-for benefits, thereby supporting the rest of our analysis. The conceptual framework that we propose shows that efforts towards material savings might allow reductions in working time per inhabitant while keeping labour compensation unchanged. However, such a possibility is hindered by competition over material efficiency gains.

1. Introduction

The need for sustainable development was officially acknowledged more than 30 years ago (Brundtland et al., 1987) and is periodically reaffirmed by science, engaged civil society, business organisations and public institutions. At the global governance level, sustainable transitions have received increasing attention, as witnessed by various United Nations initiatives, such as Agenda 21, the Millennium Development Goals (MDGs) and Agenda 2030 with its relative Sustainable Development Goals (SDGs). Nonetheless, governance and policies have largely failed to regulate markets towards development paths, as is evident when looking at material and energy use which, despite huge improvements in efficiency, have risen alarmingly. Progress has been made, at last, in broadly acknowledging the urgent need to take action to combat climate change (see, e.g., the G7 meeting in Cornwall in June 2021). Still the question remains: why are our societies locked into unsustainable paths despite the increasing and overwhelming evidence of uneconomic growth, as Herman Daly defined it[1]?

Among the many factors, as we will see in the next section, a key role is played by society's difficulty understanding the urgency of downsizing the material scale of the economy. Only in recent years has the EU started several initiatives which include combating planned obsolescence and increasing product durability, particularly within the circular economy action plans. Product lifetimes have also attracted widespread interest from research, as shown by the recent special issue "Understanding and Managing Product Lifetimes in support of a Circular Economy" in the Journal of Cleaner Production (Bakker et al., 2021). Prolonging product lifetimes is thought of as a tool for downsizing the material scale of the economy. The aim of this paper is to discuss this idea, rather than take it for granted. In what ways and under what conditions can policies for durability be effective? Who will benefit from such policies?

* Corresponding author. Dipartimento di Economia e Management, Università di Pisa, Via Cosimo Ridolfi 10, 56124, Italy.
E-mail address: tommaso.luzzati@unipi.it (T. Luzzati).

[1] In several of his writings Daly popularised the idea that growth can become uneconomic, namely when the additional benefits from production are outweighed by its additional negative environmental and social consequences (e.g., Daly, 1999). In other words, it is against its technical definition to interpret GDP as a measure of wellbeing.

https://doi.org/10.1016/j.jclepro.2022.134836
Received 13 July 2022; Received in revised form 17 October 2022; Accepted 20 October 2022
Available online 29 October 2022
0959-6526/

To answer the above research questions, as a first step we connect two debates that are often treated separately, albeit intrinsically connected: (i) the debate about working time reduction (section 3) and that about (ii) (over)production, societal metabolism and waste generation (section 4). For this reason, there is no specific section dedicated to the literature review. Rather, we introduce for each of the two research strands the main concept and results from the relevant literature and then the temporal patterns of the EU15 countries, obtained via figures available from public databases. The reasons for the focus on the EU is given by its commitment to sustainable development and its effort to implement strategies for the transition to a circular economy, such as product lifetime which is at the core of the current study, while we restrict our empirical analysis on EU15 because they are a set of rather homogeneous mature economies for which Keynes's hypothesis on working time reduction is a better fit. We then discuss (section 5) how to conceptualise and model the effects of longer lifetime policies, namely as an exogenous positive shock on resource productivity in some sectors. This reveals that competition over the generated gains is a major barrier to higher resource efficiency to obtain more leisure time and less waste. Fig. 1 intuitively synthesises the main argument of the paper, namely that increasing product lifetimes potentially benefits both working time and material use/waste.

To sum up, the paper is structured as follows. Section 2 discusses the background, and sections 3 and 4 tackle the respective issues of working time and material indicators, also presenting the empirical evidence for the EU15 countries. Adopting a systemic perspective, section 5 outlines the potential effects of the policies aimed at reducing material input and waste. Section 6 concludes.

2. Background: the broken windows economy

As Georgescu-Roegen emphasised, humans have evolved exosomatically, creating tools and using energy sources other than food. The Industrial Revolution and its exploitation of fossil fuels allowed unprecedented levels of production and a related consumption increase, the dependence on which Georgescu-Roegen did not hesitate to indicate as addiction (Georgescu-Roegen, 1975, p. 379). Calling for a wiser and more sober use of energy and matter in his concern for future generations and for the needs of poor countries, he proposed a "minimal bioeconomic programme" centred on avoiding waste of energy and matter, which included an increase in the durability of goods.

Already in 1850, the French economist Frederic Bastiat (1964) [1850] wrote about the "parable of the broken windows" which was popularised over a century later by Hazlitt (2008). The parable signifies that we often fail to see opportunity costs, in Bastiat's case that a glazier repairing a broken window means that another good (for example a pair of shoes) is not being produced. "The Kid" by Chaplin gives a visual example of the jobs "created" by breaking windows, when the child in question is sent to break windows so that they can then be repaired. In this type of economy, the number of actual glaziers would be higher than efficiency would recommend. Also in the 19th century, William Morris argued that to obtain and maintain profits, capitalists must sell a "mountain of rubbish … things which everybody knows are of no use" (Morris, 1886). While some authors point to the profit motive as driving much socially useless production (Kinna, 2000), inefficiency can be better thought of as arising from systemic failure. Together with many institutional economists, K.W. Kapp saw the emergence of social costs and the negative effects of economic activity as the outcome of an unregulated competitive system (Luzzati, 2009). The problem of misallocation of resources is further aggravated in an era of climate change and decline in the energy return on investment (EROI) values (Rye and Jackson, 2018; Brockway et al., 2019). The fact that such contradictions are often overlooked by mainstream economics is odd, because efficient allocation lies at the core of microeconomics, as undergraduate microeconomics handbooks explain, while macroeconomics blindly insists on GDP growth, overlooking the inefficient resource allocation generated by negative externalities.

While initial environmental concerns focused on hazardous and toxic pollution, in the 1990s awareness grew that the overall material size of economies was also a serious problem (e.g., von Weizsäcker et al., 1998) because of the exponential growth in consumption of materials starting after WWII, which now goes under the name of the "Great Acceleration" (McNeill and Engelke, 2014). Consistently, many started invoking urgent efforts for downsizing the material scale of the economy, which also underlies the degrowth movement (D'Alisa et al., 2015). Several initiatives have been proposed, including the introduction of material flow accounting indicators among the official EUROSTAT statistics (Eurostat, 2013). In addition, the strategies of preventing waste, reuse and

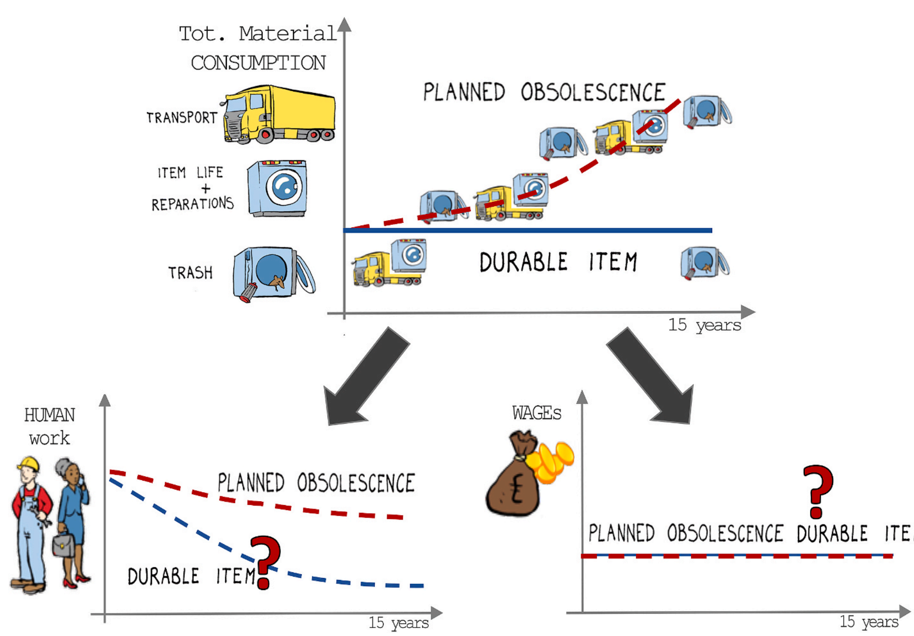

Fig. 1. A visual intuition of the argument of the paper: longer product lifetimes reduces both working time and resource consumption. (With the help of Lorenza Luzzati).

recycling have been included as core elements of the five-step waste hierarchy approach established under the EU Waste Framework Directive (2008/98/EC). Further, the European Parliament has adopted a resolution (T9-0318/2020) to encourage a culture of reuse and repair, and to devise a strategy against planned obsolescence.

At the same time, in the collective perception the need to reduce material throughput is not considered to lie at the core of sustainability principles. From the very beginning, sustainability was reduced to two main ideas, namely, 1) a balance between economy, society and environment, and 2) a concern for future generations. This is surprising since the Brundtland Commission report, published as *Our Common Future,* specifically stated that:

> "[Sustainable development] contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs." (Brundtland et al., 1987)

In *Our Common Future*, needs are at the centre of sustainability (Haland, 1999) together with the concept of limits that are the existing constraints to satisfaction of needs. On limits, Brundtland herself wrote, in a commentary to the report, that "We must tackle the myth that energy consumption must be allowed to grow unchecked" (Brundtland, 1989, p. 41). Unfortunately, the need for "material degrowth" is not fully appreciated even within those institutions that include decoupling among their goals, especially the European Union. For instance, several measures for the EU circular economy (CE) seem to overlook that recycling often requires extensive energy use. While CE proposes to mimic nature, it does not stress enough that natural cycles are closed thanks to solar energy (de Man and Friege, 2016).

To summarise, a substantial reduction in material throughput is urgently needed, and sustainable transitions are required to stop the current throwaway economy. Unrepairable short-lived products quickly become garbage, which involves a huge waste of materials, working hours and resources in general. Clearly, as was also stressed by the "Beyond GDP Debate" (EC, 2013), it should be widely acknowledged that GDP only measures the size of the market plus the cost of public administration, rather than wellbeing, and that its exponential growth is not a precondition for efficiency and material consumption changes (Andreoni and Galmarini, 2014).

3. Working time reduction: a Keynesian dream?

Just before the Great Depression, J.M. Keynes gave a lecture entitled the "Economic possibilities for our grandchildren'' which was published some years later. In this famous essay he affirmed that technological progress would provide a great increase in material wellbeing and liberate humans from the need to work. In particular, he predicted that in one century the working week of his country would be no longer than 15 h (Keynes, 2010 [1931], p. 329). Keynes's intuition did not come true. On why he was wrong much has been said and the most frequent answer points to the role of socially generated needs (consumerism) and insatiability of wants (Pecchi and Piga, 2010).

This section aims to assess the trends observed since WWII in the EU15 countries. To this end, we propose to avoid using the indicator that is commonly used, hours per worker. The reason is that part of the population has been progressively freed from labour, such as younger people who can study for longer and the elderly who can enjoy an extended retirement; also, paid holidays, part-time and temporary contracts, and female participation in the labour market have increased. The indicator "hours per worker" does not allow us to assess to what extent technological progress has enabled those changes rather than promoting a shorter working week.

A first outcome from using hours per inhabitant is a correct assessment of Keynes's prediction error. Weekly hours per worker in the UK averaged about 49 (Hart, 2019, p. 8) when Keynes wrote his essay, while about 41 in the 1950s,[2] which corresponded to 19.4 h per week per person (all population included). Since, despite some fluctuations, the ratio between workers and population remained similar to that of the 1950s, Keynes's guess of a threefold increase in labour productivity in 100 years would correspond roughly to 7 h per week per person in 2030, while the average for the period 2015–2019 was more than double (about 15.5 per person, and 32 h weekly per worker).

Looking at the evolution in time provides a more useful picture. Here we focus on the EU15 countries because they have reached a mature phase of development, for which Keynes's claim of working time reduction is more plausible. Data from the Penn World Table 10.0 (Feenstra et al., 2015) allow long-term comparisons for the EU15 from 1950 until nowadays. In Fig. 2 we plotted the time series of the average working hours per 7 days. The left-hand panel shows the average per person for the EU15[3] countries (continuous line), while the shaded red area includes the data for all countries, where the upper (lower) bound is associated with the maximum (minimum) value reported in a specific year and country. The right-hand panel focuses on a selection of countries (UK, France and Italy) for the period 1951–2019.

The average EU15 working time per person decreased until the 1980s and became stable thereafter. This is temporally associated with the wave of neoliberalism that progressively became mainstream in the wake of Margaret Thatcher's UK governments (1979–1990) and Ronald Reagan's US presidency (1981–1989) (on neoliberalism see, e.g., King and Wood, 1999). Working time then stopped decreasing long before the intense globalisation that occurred in the 2000s (when China entered the WTO). The same dynamic characterised all of the EU15 countries with two exceptions. Weekly working hours per person fell in Sweden from about 18 in 1950 to 14 in the early 1970s, reverting to 18 in 2019, while in Greece the declining trend was almost linear from 20 to 12 h during the considered time-period, probably due to a fall in overall production and employment.

In Fig. 3 we consider the period between 1995 and 2019. We took data from the EU KLEMS database, http://www.euklems.net/. The red line represents weekly (7-day) working hours per inhabitant, while the blue line represents weekly working hours per worker (employees plus self-employed; see OECD, 2001, pp. 39–43). To highlight regional heterogeneity, we also drew the trends of the countries that, for most of the time, showed the minimum and maximum values in each series.

On average, worked hours per inhabitant fluctuated around a value of 14 h per week (bottom lines of Fig. 3) while hours per worker showed a moderate, but constant decline - from about 32 to 30.5 per week. Upper and lower bounds differ, depending on which indicator is examined. Regarding hours per inhabitant, France is the lower bound, with an average of about 13 h per week, while Luxembourg is the upper bound, with an increasing trend from about 16 to more than 20 h per week in 2019. For hours per workers, Denmark and Greece are the lower and upper bound, respectively. In both cases, they show slightly declining trends with an average of about 27 and 40 h per week, respectively.

Fig. 4 suggests that the potential for reducing the working time per inhabitant has not been exploited. We plotted the cumulative growth, normalised with respect to 1995, of real GDP, real labour compensation, number of inhabitants and workers. All the variables are expressed in terms of working hours, stating respectively how much GDP is produced in an hour of work, hourly labour compensation, the reciprocal of average working time, and how many inhabitants a society can sustain with an hour's work. Real employee compensation per employee

[2] Our own calculations from the PENN World Table 10.0.https://febpwt.webhosting.rug.nl/Dmn/AggregateXs/VariableCodeSelect

[3] For Luxembourg, which is usually considered an outlier due to its peculiarity, data are available from 1971 onwards. Hence, we excluded it from this Figure.

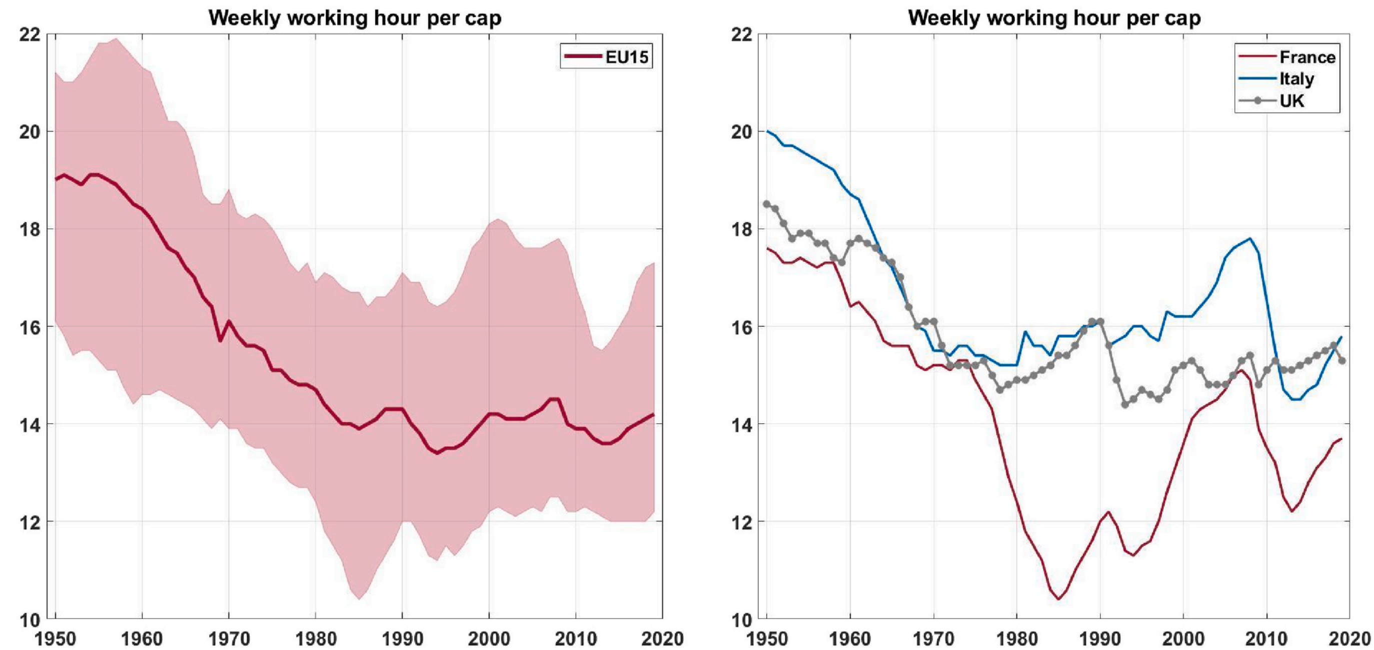

Fig. 2. Weekly working hours per person in the EU15 (excluding Luxembourg), from 1951 to 2019
The left-hand panel plots the time series of the average working hours per 7 days in EU15 (continuous line). The shaded red area includes the data for all countries, where the upper (lower) bound is associated with the maximum (minimum) value reported in a specific year and country. Source: PENN World Table, own calculations.

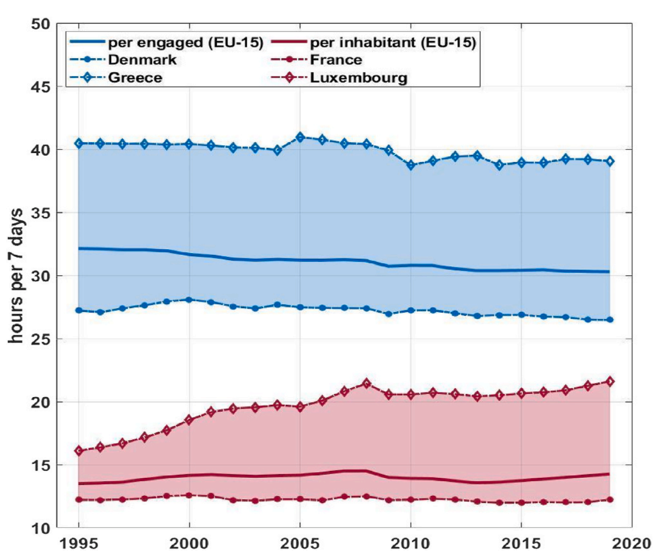

Fig. 3. Weekly working hours in EU15, from 1995 to 2019
Blue (red) line indicates the average number of *hours* per *7 days* in EU15 undertaken by workers (total population). Top (bottom) dotted line indicates the country that reported maximum (minimum) values most of the time. Source: PENN World Table, own calculations.

working hour[4] (grey line) has increased by almost 25%, indicating that 1 h of work has been receiving growing compensation. At the same time, also the real GDP per hour (green line) has increased at a faster rate (more than 50% in 23 years), which is in line with the productivity compensation gap that has been observed in the OECD countries (Criscuolo and Schwellnus, 2018; Pasimeni, 2018; Schwellnus et al., 2017). This means that distribution of the value added produced in 1 h has been going in favour of profits and rents. Hence, the fact that the benefits of increased productivity have mostly gone to companies might explain why technological progress, which is currently higher than Keynes's expectations, did not translate into a dramatic working time reduction. At the same time, the trend of the variable "population over the number of worked hours" (red line) has fluctuated around a somewhat constant value (corresponding to 14 h shown in Fig. 2), meaning that 1 h of work per day supports half a person. These facts suggest that the increase in compensation and GDP has not translated into a reduction in working hours, since the annual hours worked by employees/self-employed in EU15 increased by more than 11% over the period in question. Hence, we show that, even in rather recent times and in a set of mature economies like the EU15 countries, the opportunities for reducing working time at the whole society level have not been exploited.

Let us now turn to the huge literature on working time reduction which, however, mainly focuses on hours per worker, overlooking the question concerning to what extent increasing productivity has ended up reducing the amount of paid work in the whole economy (e.g., number of students, days off, retired workers). Working hours per worker have decreased substantially in the last 150 years (e.g., Messenger et al., 2007). Part of the success in reducing working hours (per worker) lies in increasing labour productivity due to technological progress and structural changes such as the transition from the industrial to the service sector activities with higher value-added generation. The net result of labour productivity growth is that fewer people are needed to produce the same amount of goods. However, labour productivity growth is an endogenous dynamic of capitalism, and it is emerging from the concentration of wealth and in the pursuit of overproduction (Mair et al., 2020).

Under closer inspection, recent decades have shown a bifurcation of working hours, with substantial portions of the global workforce working either very long hours (more than 48 h per week), particularly

[4] Due to the lack of data, we use labour compensation for employees, as provided in KLEMS.

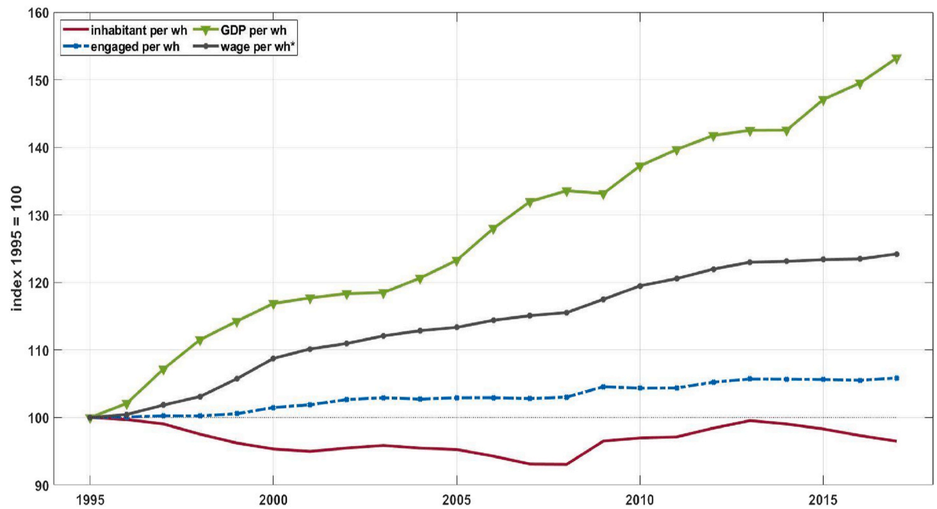

Fig. 4. Socio-economic statistics per hour worked in EU15
Cumulative change from 1995 of real GDP per worked hours, employees' labour compensation per hours worked by employees (wh*), engaged persons (both employees and self-employed) per worked hours by engaged (wh), and population per worked hours. Source: PENN Table and KLEMS, own calculations.

men, or short hours/part-time work (less than 35 h per week), predominantly women (De Spiegelaere and Piasna, 2017; Messenger, 2018). In some affluent countries, greater inequality has been found to be associated with longer work hours (Bowles and Park, 2005). Moreover, although in the richest OECD countries the standard working week is still around 40 h, there is remarkable cross-country heterogeneity: from a minimum of about 1400 yearly hours per worker in Denmark to more than 2100 in Mexico.

All in all, the evidence on working time is mixed due to gender and skill gaps. Ramey and Francis (2009) showed that hours of work are essentially unchanged, with the rise in women's hours fully compensating for the decline in men's hours and that average annual lifetime leisure increased by only four or 5 h per week during the last 100 years in the US. Costa (2000) found that the most highly paid worked fewer hours than the lowest paid in the 1890s but that by 1973 differences in hours worked were small and by 1991 the highest paid worked the longest day. Huberman and Minns (2007) provided evidence that since 1870 the decline in weekly and annual hours was greater in the Old World; the New World has had fewer days off for the last 130 years. Finally, as recounted by the EU15 data which we present, reductions in working hours per employee are found to be higher than those per person (Kallis et al., 2013).

4. Social metabolism in the EU15 countries

This section presents data concerning the social metabolism of the EU15 countries. First, however, it might prove useful to recall what this concept involves and why it is important for our purposes. A consolidated research strand studies the material exchange between the economy and the natural environment; in analogy to living systems, needing material intake from the environment, and returning waste to it, the subject of our research is termed social (or societal) metabolism. Martinez-Alier (1987) traces back this way of considering the interrelations between human and environment to Geddes, in the late 19th century, who inspired authors such as Pfaundler and Popper-Lynkeus a few decades later. Contemporary studies have drawn inspiration from the seminal paper by Ayres and Kneese (1969). Nicholas Georgescu-Roegen (1971) contributed to the foundations of the metaphor, emphasising that, by transforming concentrated materials and easily available resources into products and wastes, the economic process increases material degradation and entropy. The concept of social metabolism has since received growing attention from a wide range of studies in the fields of Industrial Ecology and Ecological Economics (some seminal ones are Adriaanse et al., 1997, Fischer-Kowalski, 1998, Weisz et al., 2002, Giljum and Eisenmenger, 2004), which empirically analyse the materials and energy flows going through socio-economic systems.

Many key concepts concerning economic growth and sustainability have been pointed out thanks to the notion of social metabolism, especially the need for material down-scaling. Since low entropy is a necessary condition for usability, the entropy production associated with material dissipation will become a limiting factor for economic growth (Kaberger and Mansson, 2001). Moreover, by increasing entropy any transformation process can damage environmental sustainability, whether generating pollution or reducing resources availability (Bianciardi et al., 1993). The larger the scale of the economy, the greater becomes the risk of compromising the conditions for human life on earth.[5] Since biophysical limits exist, economic systems should have an optimal scale relative to the total ecosystem, and a reduction in the scale of social metabolism is widely held to be a prerequisite of sustainable development (Hinterberger et al., 1997).

The field has developed to such an extent that material flows accounting has entered the official statistics, not only in the EU, but also in the UN System of Environmental-Economic Accounting (SEEA).[6] For this analysis, the most relevant indicator is the raw material consumption (RMC), better known as footprint (MF). This indicator has not yet entered the official statistics because it comes from highly uncertain estimates. MF is based on Domestic Material Consumption (DMC), an official indicator that records the annual quantity of raw materials domestically extracted plus the physical commercial balance (in terms of weights) without including the materials extracted to produce traded goods. Hence, the DMC of a net importer country tends to underestimate its actual material footprint, because many goods are produced with raw materials extracted abroad. MF is estimated by adjusting the weight of processed goods traded internationally by estimating the corresponding raw material extractions they need.

The most reliable and comprehensive database is the Global Material

[5] Already in 1950, KW Kapp warned against the incompatibility between an unregulated competitive economic system and human survival (see, e.g., Luzzati, 2009).

[6] See https://seea.un.org/content/material-flow.

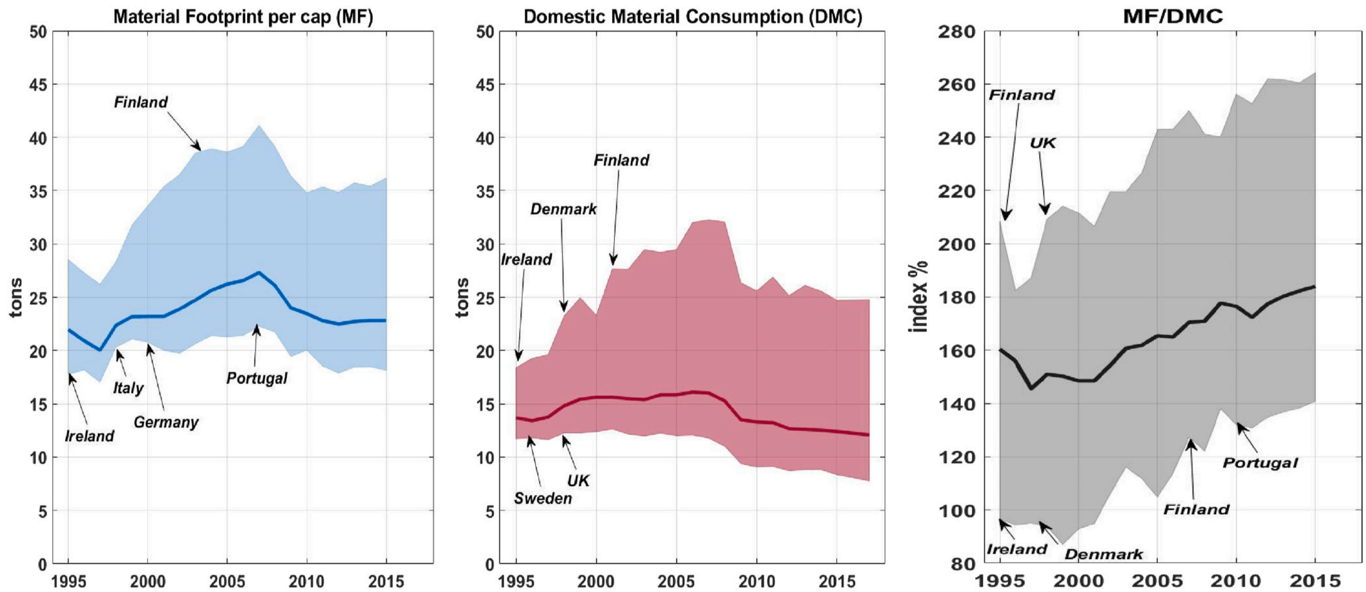

Fig. 5. Material footprint, domestic material consumption and MF/DMC ratio in the EU15 from 1995 to 2015: per capita values
Continuous lines indicate the average for the EU15. The top (bottom) dotted line indicates the country that reported maximum (minimum) values most of the time.
Source: PENN World Table, own calculation.

Flows Database, available at the UNEP International Resource Panel,[7] which we used for showing the trends of per capita RMC, DMC and the ratio between the two for EU15 in the period 1995–2015 (Fig. 5). The continuous lines indicate the values for EU15, while each country has trends included in the shaded areas.[8] To analyse the content of Fig. 5, let us start from the right-hand diagram, showing that the MF has increased compared to the DMC, revealing the EU15's increasing dependency on material extracted abroad. The central and left-hand diagrams show the time series of the DMC and MF. Both reveal a growing trend for the period that preceded the 2008 crisis. After the crisis, DMC decreased, while MF first decreased and then remained stable.

Fig. 6, for which we used data from Eurostat, shows the output side, summarised by wastes. The time span goes from 2004, the first year for which homogeneous time series were available from Eurostat. The chart on the left shows that waste generation (WG) per capita has slightly increased, while that on the right shows a significant increase in terms of the WG/DMC ratio which between 2004 and 2016 rose from 28% to almost 40%. The increase in waste generation per capita seems to contradict the idea that the service sector, which is highly developed in higher income countries, brings overall lower material intensity. In fact, services require more matter than may be intuitively expected, also because we tend to overlook the energy requirements (for computers or commuting, for instance).

Interestingly, the Eurostat website[9] makes it possible to build personalised Sankey diagrams connecting inputs to outputs for different European countries. In Fig. 7, the diagram for the year 2015 is reported for the aggregate EU15 countries[10] and the largest part of inputs is returned to the environment not as solid wastes but as emissions.

5. Increasing material efficiency for reducing both working time and material throughput

5.1. The general argument

The data for the EU15 shown in the previous sections (but also those for many other countries) are consistent with the idea that contemporary rich economies are based not only on producing useful goods, but also on "breaking windows". This has become a fairly well-established idea, to the point that institutions like the European Parliament and Commissions approved several circular economy measures for fighting planned obsolescence and improving resource productivity, including preventive actions for saving materials. In the following, we first briefly recall the main pillars of such measures and then discuss the conditions under which they can be effective, and the implications for working time and leisure.

In the last 10 years, the European Parliament has acknowledged that planned obsolescence is a very serious problem. Usually, planned obsolescence affects the durable consumption goods, such as smartphones, TVs, dishwashers, and clothes. In this direction, the report of the EU Parliament, "On a longer lifetime for products: benefits for consumers and companies" (2016/2272 (INI)), indicates that the Commission must act by encouraging the design of robust, durable, and high-quality products and the promotion of reparability and longevity of durable goods and fight planned obsolescence. Such an approach has entered the more recent and more complete "Circular Economy Action Plan" (EU Parliament, 2020). The EU will intervene in "improving product durability, reusability, upgradability and reparability, addressing the presence of hazardous chemicals in products, and increasing their energy and resource efficiency", all of this considered in a more detailed plan of circular economy that will try to connect both final consumers and producers. The problematic issue is that, in general, planned obsolescence is a strategy for firms which operate in a market that exhibits a strong degree of monopolistic behaviour, such as oligopolies (e.g., the ITC market). In all probability, not only is legislative action on the characteristics of final goods required - and we know the EU is moving in this direction - but also in-depth consideration on how to ensure greater competition on the market: a more competitive environment may reduce the incentive for such practices (if firms compete

[7] See https://www.resourcepanel.org/global-material-flows-database.

[8] The highest per capita values refer to Luxembourg, which however is an outlier for several reasons, the most important being the high rate of commuters from neighbouring countries. Hence, its values are considered for drawing the shaded areas.

[9] https://ec.europa.eu/eurostat/cache/sankey/circular_economy/sankey.html.

[10] The Sankey diagram shows only data but not the size of the flows when the UK is included. For this reason, Fig. 7 does not include the UK.

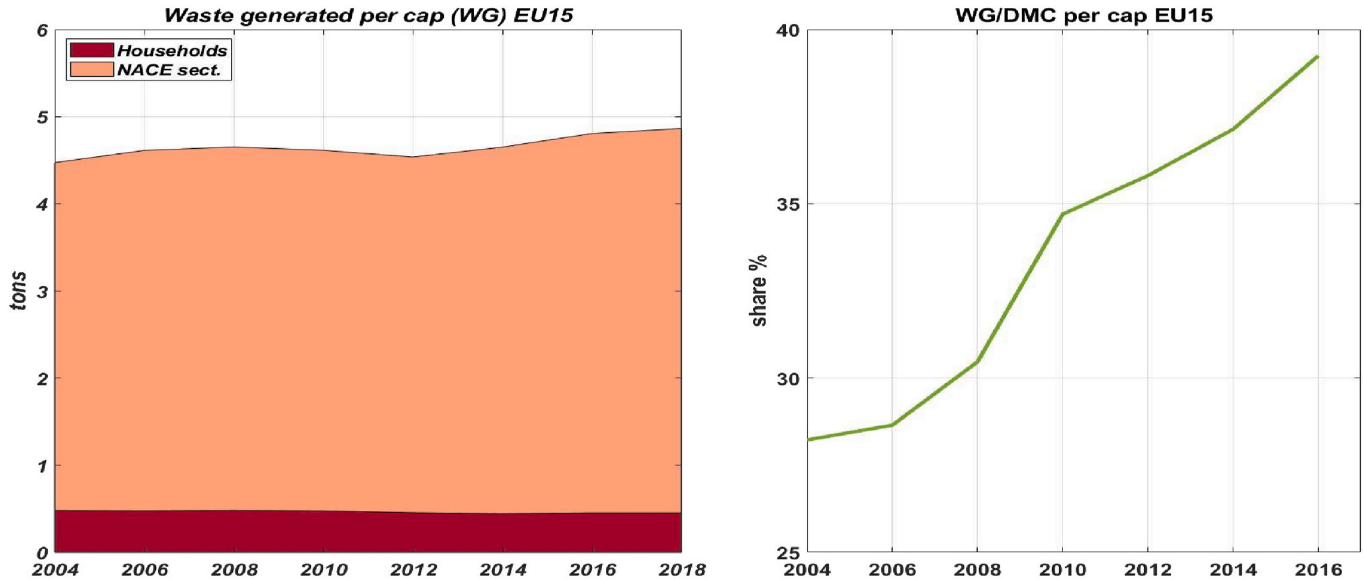

Fig. 6. Waste generation (WG) per capita and WG/DNC ratio in the EU15, from 2004 to 2015, per capita values
Continuous lines indicate the average for the EU15. The top (bottom) dotted line indicates the country that reported maximum (minimum) values most of the time. Source: EUROSTAT, https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen. Our own calculations.

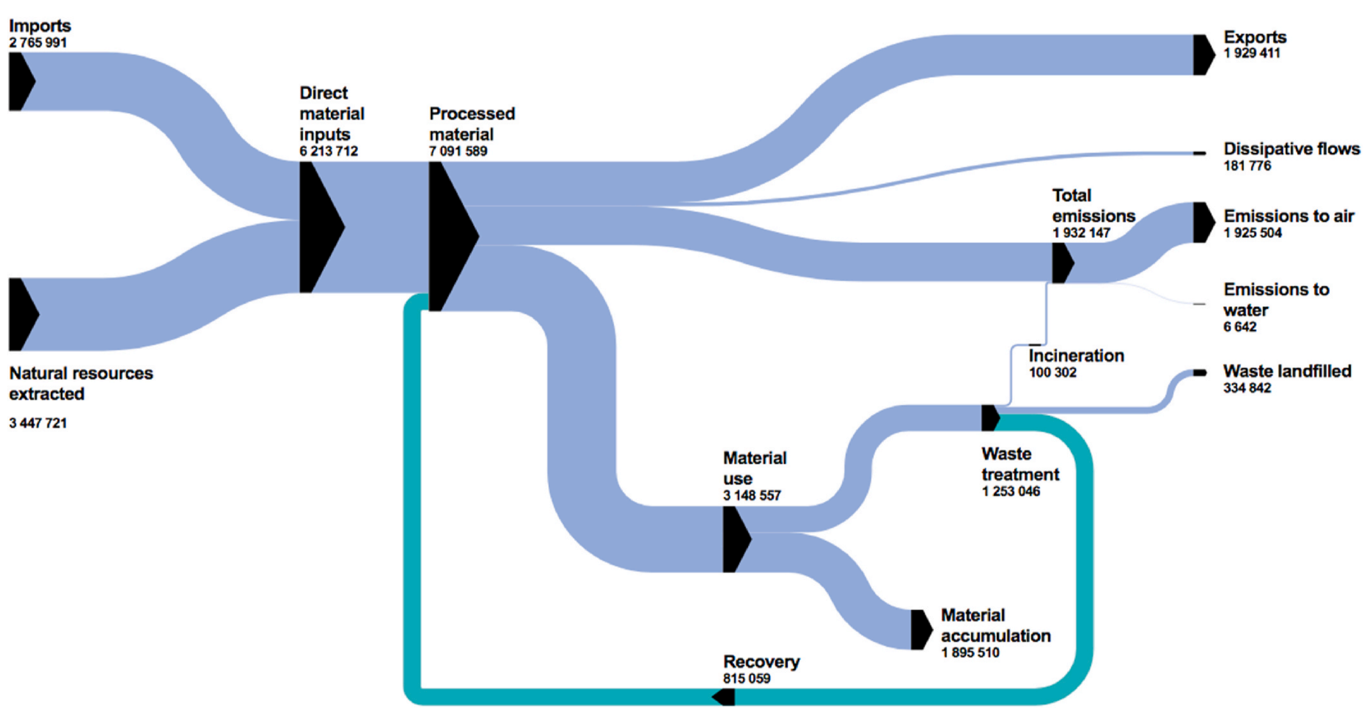

Fig. 7. Sankey diagram of Input-Output material flows for the EU15 minus the UK, for the year 2015. Source: EUROSTAT.

on the duration of their final durable consumption good). According to the EU 2016 survey, "80% of EU consumers desire more durable and reparable consumption goods". Hence the problem regards mainly the production side of the economy, and economic actors are usually driven by incentives. At a first glance, this kind of policy approach might be highly beneficial in reducing waste and abating pollution. Is such an idea correct and to what extent? And, moreover, who will benefit from this policy action?

We would like to stress that in many instances no new research or costly innovation is needed for increasing the lifetime of products; rather it would suffice to redesign them. Of course, planned obsolescence goes in the opposite direction. Although there may be several strategies to ensure longer product lifetimes, such as reparability, circular design, reuse and refurbishment, we decided to keep the level of analysis more general without going into detail. Indeed, our main aim is to focus on the possible impact of longer product lifetimes given the linkage between material use and working time, regardless of a specific intervention. For this reason, we start from an example which involves material resource saving, although not via a durability increase, or requiring almost any industrial adaptation.

Suppose that a new law imposes doubling the concentration of liquid laundry detergents.[11] What socio-economic and environmental consequences will be generated? For the sake of simplicity, imagine that firms choose to keep the price of a detergent bottle unchanged[12] by using 50% smaller bottles. This involves an almost corresponding reduction both in packaging requirements (except for the cap and some effect of the square-cube law on the bottle) and in transportation to the retailers. On the environmental side, the quantity of energy and materials required, emissions and plastic waste will be almost halved. In the negatively affected industries (packaging and transportation), turnover will decrease, existing capital will become underutilised and labour unemployed, generating lower prices of plastic bottles and transport, and, if the sector is not very small, some downwards pressure in the hourly wages at the economy level. In the detergents industry costs will become lower because their inputs per unit of production will be lower, both in volumes and prices; operating profits will increase, which will make the industry attractive to new entrants. This competitive pressure will exert a downward pressure in the price of detergents which, however, will generate only a moderate increase in detergents demand (and sales) since it the price demand elasticity for detergents is reasonably low. Hence, households will be left with more income for buying other goods and/or work less; at the same time, the income of households working in the negatively affected industries will become lower because of the already mentioned increases in unemployment. Also, wages might decrease, particularly in the countries where collective bargaining is weak. In any event, the extent to which the depressive effects of lower prices, wages and disposable income will propagate from the plastic bottle and transport industry to the rest of the economy is an empirical issue that depends mainly on the inter-industrial links, labour structure and practical implementation of the policy.

In sum, higher resource efficiency in one sector increases real productivity of all factors (labour, capital and raw materials) such that the demand for factors decreases. Cost reductions will increase operating profits and foster industry competition. This will lower product prices, provided the demand elasticity is not too low as compared to the supply elasticity. The degree of competition, the size of the affected sector and the nature of the good (its demand elasticity value) are relevant to determining both the price decrease and the final effects of the process and its beneficiaries. For instance, the policies would not entail high material savings if high elasticity generates higher demand for the goods.

5.2. A possible formalisation and strategies for research

The previous arguments can be visualised in a formal framework. We propose here a very simple two-sector model of the economy, where two goods, *C* and *D*, are produced. The first is a standard bundle of consumption goods, while *D* indicates goods that can be affected by resource efficiency policies, such as those aimed at tackling planned obsolescence and increasing product lifetimes. Production uses labour (*L*), capital (*K*) and natural resources (*R*). The production functions (Equation 1 and Equation (2)) keep the roles of *R* separate from *L* and *K*, whose contribution is expressed by *f( )* and *g( )* for *C( )* and *D( )*, respectively. This distinction is needed to recall that substitution between what Georgescu-Roegen called "fund elements" (*K* and *L*) is easier than that between funds and flows, elements that are more easily thought of as complements rather than substitutes. Resource efficiency is indicated by τ. Policies such as those discussed above would increase its value. Efficiency might be different for fund elements and resource use, indicated respectively by two different parameters τ_f and τ_R in Equation 2.[13] In the liquid detergent example, it may be assumed that an increased concentration affects all production factors (almost) in the same way, hence it can be modelled as Hicks-neutral technical progress with a unique τ which would double if concentration doubles. What is important to stress is that *D* can be thought of as the liquid detergent used in the above arguments, or as services from "durable" goods. In either case, the effect of the policies is to change the sectoral resource efficiency.

Equations (3) and (4) indicate the total amount of capital and labour force used in the two sectors. The inequality ($\geq$) means that input factors do not need to be fully employed (K^{max} and L^{max}), depending on which theoretical framework one adopts, while Equation (5) is for assuming that all extracted resources are used (to add an extractive sector would not be useful to the argument).

Equation (6) tells us that each household (indicated by *j*) has some preferences over consumption goods, durables and leisure. L indicates working time, the maximum of which is set to 1 such that leisure time is 1-*L*. Negative externalities (*E*), which are not under the control of the single household, arise because of the pollution generated by resource use (*R*). Equation 7 is the usual budget constraint: the left-hand side is the expenditure for buying *C* and *D* at their respective prices of p_C and p_D while the right-hand side tells us that income comes from selling the services of the production factors each household owns, where r is the price of the capital services, w is the wage rate, p_R is the price of the resources, and π_C and π_D are the profits from the shares held in the two sectors. The mainstream framework models consumer choice as maximising Eq. 6 subject to Eq. (7), the budget constraint. The actual modelling, however, is relevant in empirical studies (see the next subsection), while here it suffices to recall that individuals face a trade-off between consumption and leisure and that using resources reduces their wellbeing via negative externalities.

Finally, equations (8) and (9) indicate the aggregate profits in the two sectors.

Aggregate production

$$C = C\left(f(K_C, L_C), R_C\right) \quad [1]$$

$$D = D\left(\tau_f g(K_D, L_D), \tau_R R_D\right) \quad [2]$$

$$K^{max} \geq K = K_C + K_D \quad [3]$$

$$L^{max} \geq L = L_C + L_D \quad [4]$$

$$R = R_C + R_D \quad [5]$$

Individual household (j)

$$U^j = U\left(C^j, D^j, 1 - L^j\right) * E(R) \quad [6]$$

$$p_C C^j + p_D D^j = rK_i + w_i L_i^j + p_R R_i + \pi_C + \pi_D \quad [7]$$

where $i = C, D$

Representative firms

$$\pi_C = p_C C - r_C K_C - w_C L_C - p_R R_C \quad [8]$$

$$\pi_D = p_D D - r_D K_D - w_D L_D - p_R R_D \quad [9]$$

The consequences of an increase in resource efficiency in one sector would end up in a new composition in the bundle that households consume. Even if *D* remained about the same, the change in relative prices and income might favour either *C* or *L*. Also, the price of raw

[11] The reason why liquid detergents are very diluted seems to be due to marketing reasons (see, e.g., Corbett, 2014).

[12] Water is very abundant in liquid detergents, usually ranging between 60% and 90% (Corbett, 2014).

[13] In our detergent example, the increase in concentration affects all production factors almost in the same way. Hence we would have a Hicks-neutral technical progress with a unique τ.

materials will decrease, allowing consumption of goods to increase but also longer leisure times.

5.3. Strategies for empirical research

The above formalisation is useful to conceptualise the issue, especially for showing that the policies under discussion can be conceived as a positive shock to one sector of the economy. What their effects will actually be is intrinsically an empirical problem that can be tackled with very different methodologies. We briefly review them below.

First, Computational General Equilibrium (CGE) models have been used to assess how the economic system may react to specific policies (Grepperud and Rasmussen, 2004), i.e., by means of comparative static exercises (how the economy changes when some exogenous parameter changes). This approach seeks a computational analytical solution to find the general equilibrium that emerges, assuming specific functions representing the behaviour of the economic agents that are supposed to be rational. Such functions include different characteristics of substitutability between inputs (production function), or various configurations of consumer preferences (utility function). Having solved the equilibrium, comparative static exercises may be performed: imagine for example that a policy against planned obsolescence is able to raise the economic efficiency of capital (it can be viewed as an innovation from a pure economic viewpoint); an exogenous increase in capital efficiency has an effect on the whole economy, which can be seen computationally simply by changing the magnitude of the parameters of interest. The dynamic version of CGE is represented by Dynamic Stochastic General Equilibrium (DSGE) models that include adjustments due to an exogenous change in structural parameters, accounting also for the presence of stochasticity (Freire-Gonzalez and Ho, 2018).

Although CGE and DSGE are widely used, they present several shortcomings - e.g., optimising behaviour, exclusion of out-of-equilibrium dynamics, perfect competition, among others - that might undermine their reliability to indicate appropriate policy response (Stiglitz, 2018). These shortcomings call for different approaches that attempt to consider complexity, non-linear dynamics, uncertainty, agents' heterogeneity and the institutional context (Hafner et al., 2020). Such models are mostly based either on Input-Output tables, or system dynamics (Chaudhary and Vrat, 2020; Franco, 2019), or both (Towa et al., 2020).

Studies on circular economy and waste management are usually based on so-called Environmentally Extended Input-Output (EEIO) analysis that deals with the quantification of environmental pressures that take place along the supply chain of goods and services, by assuming that the production structure remains fixed (Donati et al., 2020). Nakamura and Kondo (2002) first introduced the waste-extended IO model to connect monetary flows of products and services between sectors with physical waste flows generated and treated. The main advantage of using hybrid IO models (Towa et al., 2021) is the possibility to trace and quantify the physical volumes (e.g., TJ of energy, ktoe of air emissions, kton of waste, etc.), the monetary values of intersectoral and final trade, and the social side consequences of a given economic structure (e.g., income inequality, distribution of the value added between wage and profits, wage gender gap, sustainability of the pension systems, etc) in space and time. The EEIO models have been further extended to include the dynamic of the economic system (Nakamura and Kondo, 2018). Implementing dynamic recursive in IO models permits us to assess the use of materials over time and the implications of extending the lifetime of products. For instance, it has contributed to trace the fate of materials (mostly metals) over time and across products (such as automobiles) in recycling (Pauliuk et al., 2017). Finally, the combination of the system dynamic approach - i.e., inclusion of feedback effects, multidimensional analysis, emergence of new properties due to interactions, etc. - allows implementation of scenario analysis on the short- and long-term aftermaths of both socio-economic and energy-environmental policies (D'Alessandro et al., 2020).

However, regardless of what methodology is used to explore the subject in depth, the main message of this section is that competition over the gains generated by the higher material efficiency promoted by circular economy policies is a major obstacle to converting potential material savings into lower material throughput and longer leisure time. In our example about the detergents, since the amount of money paid by households for buying the detergents would remain more or less unchanged, an increase in the price of the goods such as to leave the price per unit of service unchanged allows the income of all factors involved in the whole production chain to be kept unchanged, despite a reduction in their use. How to redistribute such efficiency gains to the other industries is the key issue for the policies aimed at saving materials to succeed whilst avoiding higher unemployment and lower labour compensation.

6. Conclusion

This study attempted to connect the debate on working time and that on material throughput, with a special focus on data from the EU15. An integration of the two issues is needed because, on the one hand, the time devoted to work per capita remains high despite technological achievements and increased efficiency and, on the other, the "great acceleration" (McNeill and Engelke, 2014) has caused unprecedented upheavals to the human environment.

The literature on working time reduction and our analysis of trends in the EU15 countries (Section 3) not only confirm that Keynes's guess about a threefold decrease in working time in one century is far from becoming true, but also that the reduction in working time in the EU15 stopped in the 1980s. We argued in favour of using working time per inhabitant as the appropriate indicator rather than the working time per worker, which is the most widely used indicator despite being deeply affected by changes in the labour force structure, such as longer retirement periods, delayed working entrance, higher female participation and changes in employment types (part-time, temporary jobs). Indeed, the two indicators show different trends. Since 1995, in the EU15, while working time (per worker) has moderately declined, working time per inhabitant has remained somewhat unchanged. Such figures contrast with the increase in labour compensation per hour and the higher increase in the GDP per hour, thereby showing that the opportunities for reducing working time at the society level have not been exploited. This cannot be attributed (solely) to a stronger preference for working and consuming over leisure time driven by consumerism, as claimed for instance by the debate on Keynes's prediction mentioned in section 3. A major factor is rather the increase in the productivity-compensation gap (at least) in the OECD countries, involving a distribution of the value added in favour of profits and rents, which also holds for the EU15 countries analysed in this paper.

On the material side (Section 4), in the EU15 from the 1990s to the great recession in 2008, domestic material consumption (DMC) remained fairly stable, while material footprint (MF) increased, showing a growing material dependence on international trade. Since 2008, MF somewhat has levelled out while DMC has started to decline. Finally, solid waste generation has increased, except for a temporary slowdown after the great recession. After all, EU15 countries are experiencing a mild shift towards less material-intensive consumption, which parallels the stability in the number of hours worked per inhabitant.

Thus, both the literature review and data suggest that policies centred on reducing material waste and increasing leisure have scope and are viable, as suggested 50 years ago by Georgescu-Roegen in his minimal bioeconomic programme. Section 5 showed that such policies can be conceptually framed as positive technological shocks hitting some specific sectors. While the economy could benefit from such a surplus, this might not occur depending on how these resource savings are redistributed to the other sectors. The literature on degrowth and post-growth has emphasised the possible existence of rebound and the Jevons effect fostered by consumerism. As is well known, the argument is that higher efficiency, by freeing up resources, will drive systemic changes that will end up reducing (or even more than offsetting) the material savings concerned (Polimeni et al., 2015).

This might not be a crucial issue here because the reduction in demand for factors in some sectors, and the implied unemployment, might offset consumer gains arising from lower prices of the products that benefited from the positive technological shock.

In general terms, we showed that one barrier to the success of policy measures aimed at prolonging product life is that the competition over the generated surplus worsens the labour conditions. Of course, in some cases a lower amount of paid work might drive the individual towards non-market activities, which are time-consuming but might require lower energy and material intensity than work[14] (Pullinger, 2014), and might increase personal wellbeing and happiness (for details on the argument see, e.g., Curtis, 2003, or Andreoni and Galmarini, 2014). Ecological economists advocate attaining both a working time reduction (Jackson and Victor, 2011) and a slowdown of labour productivity (Nørgård, 2013; Ferguson, 2016; Jackson, 2016), which is consistent with the core message of the degrowth movement that promotes "an equitable downscaling of production and consumption that increases human wellbeing and enhances ecological conditions at the local and global level, in the short and long term" (Schneider et al., 2010). However, a voluntary change in lifestyles of some people cannot be thought of as a strong enough lever to overcome the resistance to change of a society based on consumerism, in which fulfilment of given wants generates new and higher order wants (Hirsch, 1977) and consumption is so high (Huppes and Ishikawa, 2009).

Hence, measures to increase product durability need to be accompanied by policies that redistribute the material efficiency gains to the rest of the economy both by reallocating labour and reducing working times without reducing labour compensation. In other words, policies that only limit the competitive pressure to produce short-lived goods would provide firms with gains that in the end would destabilise the system if not appropriately regulated.

Finally, even from a very mainstream perspective, the wrong allocation of factors should be acknowledged, rather than insisting on the need for GDP growth, and corrected for. Indeed, temporary unemployment arising from circular economy policies can be addressed by using the increase in efficiency for promoting the reallocation of productive factors from some sectors to others. This paper suggested that there is space not only for factor reallocation, but also for reducing working time while keeping the purchasing power of the labour force unchanged.

CRediT authorship contribution statement

Tommaso Luzzati: Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Supervision. **Tiziano Distefano:** Investigation, Visualization, Writing – original draft. **Samuele Ialenti:** Writing – review & editing. **Valeria Andreoni:** Writing – review & editing.

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.

Data availability

Data will be made available on request.

[14] Any activity requires matter. Overall, very few activities have a low material intensity, particularly non-working ones like reading books (in hardcopies).

Acknowledgements

This paper received helpful insights from colleagues at the Responsible Management Research Centre (REMARC) of the University of Pisa, within which this piece of research was elaborated. We also wish to thank the two anonymous referees for their thoughtful comments and helpful suggestions, Mark Walters for his invaluable help to improve the clarity of the manuscript, and the illustrator and comic artist Lorenza Luzzati for helping with Fig. 1. Errors remain our own. The Centre for Logistics Systems (Livorno) of the University of Pisa partially supported the participation of Distefano, who also acknowledges the contribution from the "EMERITUS' MIT-UNIPI project -IX call (2021–22)".

The paper is the outcome of intense discussion among the authors. Nonetheless, the first draft of each section can be attributed as follows: section 1 and 2 Luzzati, section 3 Distefano and Luzzati, section 4 Andreoni and Luzzati, section 5 Ialenti and Luzzati, section 6 all authors.

References

Adriaanse, A., Bringezu, S., Hammond, A., Moriguchi, Y., Rodenburg, E., et al., 1997. Resource Flows: the Material Basis of Industrial Economies. World Res. Inst., Washington, DC.

Andreoni, V., Galmarini, S., 2014. How to increase wellbeing in a context of Degrowth. Future Times 55, 78–89.

Ayres, R.U., Kneese, A.V., 1969. Production, consumption, and externalities. Am. Econ. Rev. 59 (3), 282–297.

Bakker, C.A., Mugge, R., Boks, C., Oguchi, M., 2021. Understanding and managing product lifetimes in support of a circular economy. J. Clean. Prod. 279, 123764.

Bastiat, F., 1964. Selected Essays on Political Economy. Trans. Seymour Cain. Ed. George B. de Huszar. D. Van Nostrand, Princeton, N.J.

Bianciardi, C., Tiezzi, E., Ulgiati, S., 1993. Complete recycling of matter in the framework of physics, biology and ecological economics. Ecol. Econ. 8, 1–5.

Bowles, S., Park, Y., 2005. Emulation, inequality, and work hours: was Thorsten Veblen right? Econ. J. 115 (507), F397–F412.

Brockway, P.E., Owen, A., Brand-Correa, L.I., Hardt, L., 2019. Estimation of global final-stage energy-return-on-investment for fossil fuels with comparison to renewable energy sources. Nat. Energy 4 (7), 612–621.

Brundtland, G.H., 1989. Global change and our Common future. Environ. Sci. Pol. Sustain. Dev. 31 (5), 16–43.

Brundtland, G.H., Khalid, M., Agnelli, S., Al-Athel, S., Chidzero, B.J., 1987. Our Common Future. Report of the World Commission on Environment and Development. Oxford University Press. Available at: http://www.un-documents.net/wced-ocf.htm. (Accessed 12 August 2021). Accessed:

Chaudhary, K., Vrat, P., 2020. Circular economy model of gold recovery from cell phones using system dynamics approach: a case study of India. Environ. Dev. Sustain. 22 (1), 173–200.

Corbett, P., 2014. Purex Laundry Detergent to Cut its Water Content by 25 Percent. Available at: https://eu.azcentral.com/story/money/business/2014/05/13/purex-laundry-detergent-cut-water-content-percent/9049081/. (Accessed 12 August 2021).

Costa, D.L., 2000. The wage and the length of the work day: from the 1890s to 1991. J. Labor Econ. 18 (1), 156–181.

Criscuolo, C., Schwellnus, C., 2018. Decoupling of Wages from Productivity. OECD Economic Outlook.

Curtis, F., 2003. Eco-localism and sustainability. Ecol. Econ. 46, 83–102.

D'Alessandro, S., Cieplinski, A., Distefano, T., Dittmer, K., 2020. Feasible alternatives to green growth. Nat. Sustain. 3 (4), 329–335.

D'Alisa, G., Demaria, F., Kallis, G. (Eds.), 2015. Degrowth: A Vocabulary for a New Era. Routledge, Earthscan.

Daly, H., 1999. Uneconomic growth and the built environment: in theory and in fact. In: Kibert, C.J. (Ed.), Reshaping the Built Environment: Ecology, Ethics, and Economics. Island Press, Washington DC.

de Man, R., Friege, H., 2016. Circular economy: European policy on shaky ground. Waste Manag. Res. 34 (2), 93–95.

De Spiegelaere, S., Piasna, A., 2017. The Why and How of Working Time Reduction. European Trade Union Institute.

Donati, F., Aguilar-Hernandez, G.A., Sigüenza-Sánchez, C.P., de Koning, A., Rodrigues, J. F., Tukker, A., 2020. Modelling the circular economy in environmentally extended input-output tables: methods, software and case study. Resour. Conserv. Recycl. 152, 104508.

EC, 2013. Progress on "GDP and beyond" Actions. Commission Staff Working Document. SWD (2013) 303 Final. Available at: SWD_2013_303.pdf (europa.eu). (Accessed 12 August 2021).

EU parliament, 2020. Resolution T9-0318/2020: towards a More Sustainable Single Market for Business and Consumers. Available at. https://www.europarl.europa.eu/doceo/document/TA-9-2020-0318_EN.html. (Accessed 12 August 2021).

Eurostat, 2013. Economy-Wide Material Flow Accounting (EW-MFA) - Compilation Guide 2013. Available at: 2013 EW-MFA Guide (10Sep2013) (europa.eu). (Accessed 12 August 2021).

Feenstra, R.C., Inklaar, R., Timmer, M.P., 2015. The next generation of the Penn world table. Am. Econ. Rev. 105 (10), 3150–3182.
Ferguson, P., 2016. Productivity growth as a barrier to a sustainability transition. Environ. Innov. Soc. Transit. 20, 86–88.
Fischer-Kowalski, M., 1998. Society's metabolism. The intellectual history of materials flow analysis, Part I, 1860-1970. J. Ind. Ecol. 2, 61–78.
Franco, M.A., 2019. A system dynamics approach to product design and business model strategies for the circular economy. J. Clean. Prod. 241, 118327.
Freire-Gonzalez, J., Ho, M.S., 2018. Environmental fiscal reform and the double dividend: evidence from a dynamic general equilibrium model. Sustainability 10 (2), 501.
Georgescu-Roegen, N., 1971. The Entropy Law and the Economic Process. Harvard University Press, Cambridge (Massachusetts).
Georgescu-Roegen, N., 1975. Energy and economic myths. South. Econ. J. 347–381.
Giljum, S., Eisenmenger, N., 2004. North-south trade and the distribution of environmental goods and burdens: a biophysical perspective. J. Environ. Dev. 13, 73.
Grepperud, S., Rasmussen, I., 2004. A general equilibrium assessment of rebound effects. Energy Econ. 26 (2), 261–282.
Hafner, S., Anger-Kraavi, A., Monasterolo, I., Jones, A., 2020. Emergence of new economics energy transition models: a review. Ecol. Econ. 177, 106779.
Haland, W., 1999. On needs-a central concept in the Brundtland report. In: Towards Sustainable Development. Palgrave Macmillan, London, pp. 48–69.
Hart, R.A., 2019. Labor Productivity during the Great Depression in UK Manufacturing, IZA Discussion Papers, No. 12379. Institute of Labor Economics (IZA), Bonn.
Hazlitt, H., 2008. Economics in One Lesson. Ludwig von Mises Institute, Auburn, Ala.
Hinterberger, F., Luks, F., Schmidt-Bleek, F., 1997. Material flows vs. natural capital': what makes an economy sustainable? Ecol. Econ. 23 (1), 1–14.
Hirsch, F., 1977. Social Limits to Growth. Routledge, London.
Huberman, M., Minns, C., 2007. The times they are not changing,Days and hours of work in old and new worlds, 1870-2000. Explor. Econ. Hist. 44 (4), 538–567.
Huppes, G., Ishikawa, M., 2009. Eco-efficiency guiding micro-level actions towards sustainability: ten basic steps for analysis. Ecol. Econ. 68, 1687–1700.
Jackson, T., 2016. Prosperity without Growth: Foundations for the Economy of Tomorrow. Routledge.
Jackson, T., Victor, P., 2011. Productivity and work in the 'green economy': some theoretical reflections and empirical tests. Environ. Innov. Soc. Transit. 1 (1), 101–108.
Kaberger, T., Mansson, B., 2001. Entropy and economic processes - physics perspectives. Ecol. Econ. 36, 165–179.
Kallis, G., Kalush, M., O'Flynn, H., Rossiter, J., Ashford, N., 2013. Friday off': reducing working hours in Europe. Sustainability 4 (5), 1545–1567.
[1931] Keynes, J.M., 2010. Economic possibilities for our grandchildren. In: Essays in Persuasion. Palgrave Macmillan, London, pp. 321–332.
King, D., Wood, S., 1999. The political economy of neoliberalism: Britain and the United States in the 1980s. Contin. Change Contemp. Capital. 13, 371–397.
Kinna, R., 2000. William Morris: art, work, and leisure. J. Hist. Ideas 61 (3), 493–512.
Luzzati, T., 2009. Human needs, sustainable development, and public policy: learning from KW Kapp (1910-1976). In: Salvadori, N., Opocher, A. (Eds.), Long-run Growth, Social Institutions and Living Standards. Edward Elgar, pp. 306–322.
Mair, S., Druckman, A., Jackson, T., 2020. A tale of two utopias: work in a post-growth world. Ecol. Econ. 173, 106653.
Martinez-Alier, J., 1987. Ecological Economics: Energy, Environment and Society. Blackwell, Oxford.
McNeill, J.R., Engelke, P., 2014. The Great Acceleration: an Environmental History of the Anthropocene since 1945. Belknap P, Cambridge, 2014.
Messenger, J.C., 2018. Working Time and the Future of Work. Future of Work Research Series. Geneva: ILO.
Messenger, J.C., Lee, S., McCann, D., 2007. Working Time Around the World: Trends in Working Hours, Laws, and Policies in a Global Comparative Perspective. Routledge.
Morris, W., 1886. Useful Work versus Useless Toil. Socialist League Office. No. 48.
Nakamura, S., Kondo, Y., 2002. Input-output analysis of waste management. J. Ind. Ecol. 6, 39–63.
Nakamura, S., Kondo, Y., 2018. Toward an integrated model of the circular economy: dynamic waste input-output. Resour. Conserv. Recycl. 139, 326–332.
Nørgård, 2013. Happy degrowth through more amateur economy. J. Clean. Prod. 38, 61–70.
OECD, 2001. Measuring Productivity - OECD Manual: Measurement of Aggregate and Industry-level Productivity Growth. OECD Publishing, Paris. https://doi.org/10.1787/9789264194519-en. Available at: (Accessed 12 August 2021). Accessed:
Pasimeni, P., 2018. The Relation between Productivity and Compensation in Europe (No. 079). Directorate General Economic and Financial Affairs (DG ECFIN), European Commission.
Pauliuk, S., Kondo, Y., Nakamura, S., Nakajima, K., 2017. Regional distribution and losses of end-of-life steel throughout multiple product life cycles insights from the global multiregional MaTrace model. Resour. Conserv. Recycl. 116, 84–93.
Pecchi, L., Piga, G. (Eds.), 2010. Revisiting Keynes: Economic Possibilities for Our Grandchildren. Mit Press.
Polimeni, J.M., Mayumi, K., Giampietro, M., Alcott, B., 2015. The Myth of Resource Efficiency: the Jevons Paradox. Routledge.
Pullinger, M., 2014. Working time reduction policy in a sustainable economy: criteria and options for its design. Ecol. Econ. 103, 11–19.
Ramey, V.A., Francis, N., 2009. A century of work and leisure. Am. Econ. J. Macroecon. 1 (2), 189–224.
Rye, C.D., Jackson, T., 2018. A review of EROEI-dynamics energy-transition models. Energy Pol. 122, 260–272.
Schneider, F., Kallis, G., Martinez-Alier, J., 2010. Crisis or opportunity? Economic degrowth for social equity and ecological sustainability. Introduction to this special issue. J. Clean. Prod. 18 (6), 511–518.
Schwellnus, C., Kappeler, A., Pionnier, P., 2017. Decoupling of Wages from Productivity: Macro-Level Facts. OECD Economics Department Working Papers, No. 1373, OECD Publishing, Paris. https://doi.org/10.1787/d4764493-en. Available at: (Accessed 12 August 2021).
Stiglitz, J.E., 2018. Where modern macroeconomics went wrong. Oxf. Rev. Econ. Pol. 34 (1–2), 70–106.
Towa, E., Zeller, V., Achten, W.M., 2020. Input-output models and waste management analysis: a critical review. J. Clean. Prod. 249, 119359.
Towa, E., Zeller, V., Achten, W.M., 2021. Circular economy scenario modelling using a multiregional hybrid input-output model: the case of Belgium and its regions. Sustain. Prod. Consum. 27, 889–904.
von Weizsäcker, E.U., Lovins, A.B., Lovins, L.H., 1998. Factor Four: Doubling Wealth-Halving Resource Use: the New Report to the Club of Rome. Earthscan.
Weisz, H., Amann, C., Eisenmenger, N., Erb, K.H., Hubacek, K., Krausmann, F., Schulz, N. B., 2002. Economy-wide Material Flow Accounts and indicators of resource use for the EU. Eurostat Tender 2001. S 125-084782/EN. Final Report. Eurostat Working Papers. Eurostat, Luxembourg.