Universitat Autònoma de Barcelona

Recession, Working Time and Environmental Pressure: Econometric Contributions

Qinglong Shao

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Doctoral thesis

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by

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"As heaven maintains vigor through movements,

A gentle man should constantly strive for self-perfection.

As earth`s condition is receptive devotion,

A gentle man should hold the outer world with broad mind."

- From ZHOUYI

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Summary

The main aim of this thesis is to investigate the effects of working time and economic recession on the environment, especially on carbon emissions. This is attained through five original studies. The first two analyses (*chapter 2 and 3*) examine the impact of economic recession on carbon emissions and material flows. The **first** study concludes that on a global scale, at least 31.34 Gt of CO_2 emissions have been avoided due to economic recessions since 1960. Recessions are the most determinant factor of carbon reductions, but their effect alone is not sufficient to meet the objective of staying below a 2℃ global temperature change. The **second** study, based on a historical panel data analysis of 150 countries, finds that periods of recession are significantly associated with absolute dematerialization. However, the higher the growth of GDP, the less significant we have found the correlation to be. The significant correlation disappears when the growth rate is higher than 2%. Minerals and metals used in bulk for construction appear to be more sensitive to economic fluctuations than biomass and fossil fuels.

The next three contributions (*chapters 4, 5 and 6*) investigate possible linear as well as non-linear relationships between hours of work and environmental pressure. The **third** study finds a significant negative correlation between working time and environmental pressure for developed countries, which is contrary to prior research, according to which shorter working hours improve the environment. The **fourth** study advances the analysis by dividing a world sample into developed and developing country groups and splitting the research period into two phases, before and after the year 2000. The results show no significant correlation between working time and environmental burden in developing economies, however in their developed counterparts, a "rebound effect" occurs. The significant relationship between hours of work and environmental pressure turns from positive to negative after 2000, partly because residents in wealthier countries prefer more energy-intensive activities in their leisure time, such as long-distance car traveling or vacations abroad. Based on these findings, the **fifth** and final study concludes that until 2010, among the EU-15 countries, further reductions in working hours in Denmark, Germany, France and the Netherlands may start having a negative impact on the environment.

Resumen

El objetivo principal de esta tesis es investigar los efectos del tiempo de trabajo y la recesión económica sobre el medio ambiente y especialmente sobre las emisiones de carbono. Esto se lleva a cabo a través de cinco estudios originales. Los dos primeros análisis (capítulos 2 y 3) examinan el impacto de la recesión económica sobre las emisiones de carbono y los flujos de materiales. El primer estudio demuestra que globalmente al menos unos 31.34 Gt de emisiones de CO_2 han sido evitadas debido a recesiones económicas desde 1960. Las recesiones son el factor más determinante de las reducciones de carbono, pero su efecto por sí solo no marcará la diferencia en el objetivo de mantener en menos de 2℃ el incremento global de temperatura. El segundo estudio, basado en un análisis histórico de datos de panel de 150 países, encuentra que los períodos de recesión están significativamente asociados con la desmaterialización absoluta. Sin embargo, cuanto mayor fue el crecimiento del PIB, menos significativa fue la correlación. La correlación significativa desaparece cuando la tasa de crecimiento supera al 2%. Los minerales y metales utilizados a granel para la construcción parecen ser más sensibles a las fluctuaciones económicas que la biomasa y los combustibles fósiles.

Las tres contribuciones siguientes (capítulos 4, 5 y 6) investigan posibles relaciones lineales y no lineales entre las horas de trabajo y la presión medioambiental. El tercer estudio encuentra una correlación negativa significativa entre el tiempo de trabajo y la presión ambiental para los países desarrollados, lo que contradice estudios previos, según los cuales la reducción del tiempo de trabajo mejora el medio ambiente. El cuarto estudio avanza el análisis dividiendo una muestra mundial en grupos de países desarrollados y en desarrollo y dividiendo el período de investigación en dos fases, antes y después del año 2000. Los resultados no muestran una correlación significativa entre el tiempo de trabajo y la carga medioambiental en las economías en desarrollo; no obstante, en las economías desarrolladas se produce un "efecto rebote". La relación significativa entre las horas de trabajo y la presión medioambiental pasa de positiva a negativa después del año 2000, en parte debido a que las personas que viven en países más ricos prefieren actividades de elevado consumo energético en sus horas de ocio, como viajar largas distancias en coche o hacer vacaciones en el extranjero. Sobre la base de estos hallazgos, el quinto y último estudio concluye que hasta 2010, entre los países de la UE15, una nueva reducción del tiempo de trabajo en Dinamarca, Alemania, Francia y los Países Bajos puede comenzar a dañar el medio ambiente.

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List of acronyms

WTR: Working Time Reduction

PB: Planetary Boundaries

GMM: Generalized Method of Moments

sys-GMM: system Generalized Method of Moments

diff-GMM: difference Generalized Method of Moments

SMEs: Small and Medium-sized Enterprises

SSE: Steady State Economy

NDRC: the National Development and Reform Commission

Mtce: million tons of coal equivalents

FYP: Five Year Plan

NEAA: Netherlands Environmental Assessment Agency

EEA: European Environment Agency

WCED: World Commission on Environment and Development

WVS: World Values Survey

ILO: International Labor Organization

1. Introduction

1.1 General context and debates

"We've seen how a faulty economics drives and is driven by a distorted social logic. But we've also seen that a different economics is achievable. A better and fairer social logic lies within our grasp. Neither ecological limits nor human nature constrain the possibilities here: only our capacity to believe in and work for change" (Jackson 2009)

In the past decades, there has been heated debate over whether it is possible to achieve economic growth without harming the environment (Everett et al. 2010). However, this debate has been part of a wider theoretical discussion of the growth model. Contrary to the argument that environmental degradation is reversed as soon as the average income level reaches a certain threshold, as illustrated by the Environmental Kuznets Curve (Sun, 1999; Stern, 2004; Dinda, 2004; Galeotti et al., 2006), evidence now indicates that such decoupling only relates to human health (Stern 2004). Economic growth continues to be associated with biodiversity loss, climate change, and the undermining of human livelihoods at the commodity frontiers.

Since the 1950s, numerous environmental protection movements have emerged as a response to the environmental pollution caused by economic growth. The sustainable development model was first proposed in 1987, in *Our Common Future* released by the World Commission on Environment and Development (WCED). This report was the first of its kind to discuss development and the environment as one single issue (WCED 1987). Following the same line of thought, the "green economy" concept was formally put forward by the *Green Economy Report,* to describe an economy that would grow without harming the environment. Regardless of rising public concern about the environment, expressed in concepts such as "green", "ecological" or "sustainable", the above initiatives all failed to reach their aims (Martínez-alier et al. 2010). Their solutions still hinge on internalizing externalities through market instruments and eliminating distortions to trade (Gómez-Baggethun and Naredo, 2015). In light of this, it can be argued that debates on growth and the environment, as well as new concepts such as "de-growth", "a-growth" or "planetary boundaries" merit more attention.

As the saying goes, "you cannot have your cake and eat it, too". Critics of growth argue that it is not possible to grow the economy and use fewer resources at the same time; therefore, they focus their interest on how to achieve a prosperous life without growth. To conceive of prosperity in the absence of growth is essential, given that economic growth cannot to this moment be coupled with environmental protection, despite the expectations of growth proponents. It is, therefore, crucial to envision different, more sustainable patterns of economic activity, which can enrich our life without deteriorating the environment.

In the following sections, I review the literature on the limits to growth and planetary boundaries, I examine the critique of green growth, and I outline the debates around de-growth and a-growth. Next, I lay out the multi-disciplinary theoretical framework underpinning the research, and I explain the importance of focusing on economic recession and working time as involuntary and voluntary ways of mitigating environmental pressure. I then present the results of my research (*chapters 2, 3, 4, 5 and 6*) and I draw some overarching conclusions in the final chapter.

1.1.1 Limits to growth

Early debates on growth have their origins in the milestone publication *The Limits to Growth*, compiled by members of the Club of Rome, such as Donella H. Meadows, Dennis L. Meadows, Jørgen Randers, and others. The fundamental finding was that, given the public attitudes and policies at the time, the overshoot scenario was only one of many possible outcomes, and the world system was not locked into this overshoot pattern. Thus, the authors presented a comparatively optimistic picture; they appeared to suggest that it was possible to change current growth trends and build a sustainable future.

From the 1990s onwards, however, there has been increasing evidence that the environment is constantly being degraded and that the situation is getting out of control (Meadows et al. 1992). In 2004, in their 30-year update of the original report (Meadows et al. 2004), the authors reviewed their stance and warned that, despite advances in energy efficiency technologies, a multitude of environmental policies and increasing public awareness on climate change, humanity was under threat. Even though the sustainable development strategy has failed to correct the course of environmental degradation over the previous 30 years, growth proponents still seem unwilling to abandon their effort to combine environmental protection with economic growth, and have refused to take radical steps in transforming the economy. In fact, addiction to growth now seems inevitable, as it is deeply embedded in current institutions and has taken the form of an ideology.

1.1.2 Planetary boundaries

As humanity faces numerous serious problems, such as biodiversity loss and ocean acidification, “an integrated perspective to calibrate the operation of the human system so that it remains within safe parameters for a stable Earth system” (Rockström, 2015, p.1) is necessary. To help in tackling the problems, in the presentation of their innovative work in *Nature*, Rockström et al. (2009, p.472) presented a framework of “Planetary Boundaries” (PB), that can “define the safe operating space for humanity with respect to the Earth system and are associated with the planet’s biophysical subsystems or processes.” This was the first systematic empirical analysis on PB. The authors warned that the boundaries for certain environmental areas have been transgressed Rockström et al. (2009, p.473) (see **Fig.1-1**). Therefore, more elaborations on environmental protection are needed to improve the situation in these areas. An advantage of the PB approach compared to other sustainable strategies is that it can be theoretically combined with other environmental approaches, to effectively address global threats to humanity and the environment (Baum & Handoh 2014). New frameworks can be constructed by linking PB with environmental footprints (EF), which provides mutual benefits as “the planetary boundaries framework benefits from well-grounded footprint models which allow for more accurate and reliable estimates of human pressure on the planet's environment” (Fang et al., 2015, p.218).

Yet, the approach presents a number of shortcomings. One inherent defect of the PB approach is that some boundaries are inefficiently transmit from local to global levels (Mace et al. 2014), and certain factors, such as chemical pollution, are transgressing the boundaries, making the pollution control measures insufficient (Diamond et al. 2015). Therefore, alternative approaches to determining biodiversity loss boundaries should be developed. Besides, the actual location of the boundaries may be somewhat arbitrary (Lewis 2012); boundary transgression would not in all cases lead to a negative environmental impact; and, even within the threshold, climate change could be detrimental (Asara et al. 2015). In academia, *Ecological Economics* organized a special section on "Planetary Boundaries and Global Environmental Governance" (in Vol. 81, Sep. 2012). Scholars in this field presented their views and thoughts on both theoretical and empirical aspects.

New institutions that transcend the current arrangement are required if we are to achieve prosperity within the boundaries. We need, on the one hand, environmentally friendly technologies, that is, brilliant and profitable ideas, to open the pathway to a sustainable common future, and, on the other, an open transfer of technologies to the world's developing nations to promote their capacity for development (Rockström & Klum 2015). I conclude this section by citing Rockström (2015, p.7) from his recent work, published on the Great Transition Initiative website, titled *Bounding the Planetary Future: Why We Need a Great Transition*, a conclusive and forward-looking research on PB :

"The world urgently needs a great transition that rapidly bends the curve of negative global environmental change. Such a turn toward sustainability demands a deep shift in the logic of development away from the assumption of infinite growth toward a paradigm of development and human prosperity within Earth limits. It will require transformations in energy systems, urban development, food systems, and material use. Achieving all this will entail fundamental institutional changes in economic arrangements, financial systems, and world trade."

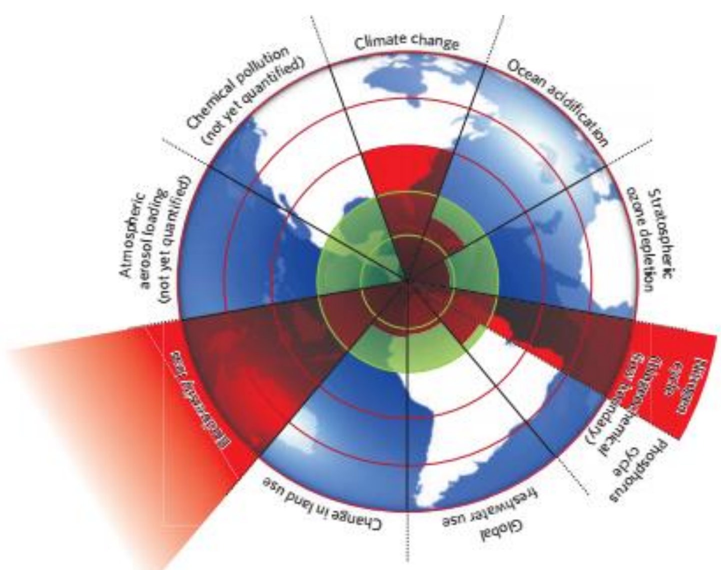


Fig.1-1. Beyond the Boundary

Source: Rockström et al. (2009)

1.1.3 Green growth

The dream of a “win-win” solution that would stimulate economic growth without harming the environment has a long history. Green growth is such a solution, as it entails “fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies” (OECD 2011). The green agenda is not confined here to economic and environmental systems but also incorporates essential human values such as biodiversity, justice and happiness (Bowen & Fankhauser 2011). Green growth, adopted at the Rio+20 meeting (UN 2012), is hotly debated in both academic and political domains. It gained momentum after the 2008–09 global economic downturn, as scholars regarded this as a golden opportunity for transforming the economy to exert less pressure on the environment. Consequently, green growth is seen as a “unique opportunity presented by the multiple crises and the ensuing global recession” (UNEP, 2009, p.4); and it “has the potential to revive the world economy and reduce its vulnerability to repeated fuel and food crises as well as climate-induced risks” (Barbier, 2010, p.20), although, in retrospect, this dream seems unrealizable.

In that context, green growth regulations and policies have widely been established at a country level. China has committed to achieving a green economy in response to its rising energy demand and carbon emissions. Energy efficiency in China, one of the main drivers for green transformation, has greatly improved at the periods of *11th, 12th and 13th Five-Year Plans (FYP)*, i.e., 2006–2010, 2011–2015 and 2016–2020 respectively. In the *13th FYP* (2016–2020), green growth is declared a main target, with the aim increasing non-fossil energy consumption to 15% and gas consumption to 10%, as well as reducing coal use to 62% by 2020 (Xinhua News Agency, 2016). Yet, these are relative accomplishments, as absolute decoupling is still unattainable. The same applies to Germany, a country that pioneered green growth policies. Germany has managed to reduce carbon emissions by 23% in 2009 relative to 1990 levels and expects to cut emissions further by 40% by 2020 and at least by 80% by 2050. Renewable energy consumption grew fivefold over the period 1990–2010, and the share of renewables is planned to surpass 80% by 2050 (OECD 2014).

However, green growth policies are proven to be ineffective. South Korea is a good case in point; in 2009, the country launched an ambitious plan named "National Green Growth Strategy" (Presidential Commission on Green Growth 2009). However, despite the high ambition and the generous green stimulus spending, income remained the main driver of CO_2 emissions, and empirical results revealed that the declared emission reductions had not taken place during the period 2009–13 (Sonnenschein & Mundaca 2016). The unsuccessful, as yet, implementation of green growth proves that it is almost impossible to simultaneously achieve GDP growth and environmental preservation. Full employment, as one of the traditional main economic aims, is very difficult to combine with green growth. A reconstruction of the whole social and economic system is thus necessary (Kallis et al., 2014).

1.1.4 A-growth v.s. de-growth

1.1.4.1 The development of "de-growth"

In light of the failure of many ecological modernization strategies (such as "sustainable development", "green economy", etc.) and the deteriorating environment, arguments that favor growth become gradually less appealing for many. As a result, an alternative to the growth paradigm has been proposed, namely, "degrowth". Emerging in the early 1970s, the degrowth paradigm has been regarded as an effective solution for a social-ecological transformation. In essence, the key word of de-growth is not *less* but *different*: "In a degrowth society, everything will be different: different activities, different forms and uses of energy, different relations, different gender roles, different allocations of time between paid and non-paid work and different relations with the non-human world" (Kallis et al., 2014, p.4). Latouche (2003, p.18) argues that degrowth is a "society built on quality rather than on quantity, on cooperation rather than on competition […] humanity liberated from economism for which social justice is the objective. […] The motto of de-growth aims primarily at pointing the insane objective of growth for growth. Degrowth is not negative growth, a concept that would be contradictory and absurd, meaning stepping forward while going backward."

Degrowth, as a multidimensional concept, acquires different meanings stemming from different backgrounds. In the economic dimension, degrowth proposes "an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, in the short and long term" (Schneider et al., 2010, p.512); human well-being is the ultimate goal (Andreoni & Galmarini 2014), and the GDP is only of secondary importance. In this respect, degrowth should be distinguished from recession, it does not necessarily mean a rise in unemployment or poverty levels. In the political arena, degrowth acts as a "political slogan with theoretical implications" (Latouche 2010). In a general sense, it is "a radical political project that offers a new story and a rallying slogan for a social coalition built around the aspiration to construct a society that lives better with less" (Kallis, 2011, p.873). Therefore, degrowth has become, as Mart ńez-Alier et al. (2010, p.1742) put it, "both a banner associated with social and environmental movements and an emergent concept in academic and intellectual circles, [which] are interdependent and affect each other".

An essential concept of degrowth is the "Jevons paradox", commonly referred to as "rebound effect". This describes a situation where improvements in energy efficiency brought about by technological progress may further aggravate environmental pressure, because consumption is stimulated in this process. In addition, degrowth challenges decoupling as a possibility to combine economic growth with material use. It is argued that even though a relative decoupling can be realized, e.g., GDP grow faster than CO_2 emissions (Jackson 2009), absolute decoupling, that is, absolute decline in CO_2 emissions while the economy rises, is not occurring (Dinda, 2004; Stern, 2004; Galeotti et al., 2006; Asara et al., 2015). Recent empirical evidence also supports the view that ultimately growth in GDP and growth in material use cannot be decoupled (Ward et al. 2016). Absolute dematerialization may only appear at recession years (Krausmann et al. 2009); this is one of the main research focal points in this thesis.

1.1.4.2 Debates on "de-growth" and "a-growth"

"A-growth" is another proposal that seeks to replace previous unsuccessful green strategies. It calls for neglecting GDP and turning attention to indicators of social welfare that are closely related to human well-being, while "being indifferent or neutral about economic growth" (van den Bergh, 2011, p.882). By contrast, de-growth proponents hold that any growth, be it slow or fast, would lead toward global environmental and economic collapse, as proposed by the Entropy Law (Georgescu-Roegen, 1971; 1987). A-growth "focus […] on sound environmental, social, and economic policies independently of their effects on economic growth" (van den Bergh and Kallis, 2012, p.909). Contrary to a-growth, degrowth regards the fetishism of growth as an ideology—or even as a religion—so deeply rooted in our society that radical structural (political/economic) and cultural changes are necessary for the transition to a real sustainable future (Kallis 2011).

Degrowth proposes that, according to historical experience, only in periods of recession have carbon emissions declined, and consequently zero growth or even negative growth is necessary to meet climate change targets. However, it is noteworthy that the long-term carbon mitigation effect of GDP decline is uncertain, as it may depress investment in cleaner technologies and renewable energy, which may, in turn, increase carbon emissions. In the short term, production in times of recession may turn into dirtier processes. If we calculate all the possible effects, the final result will depend on the offset between the two; therefore, a quantitative analysis is needed to enrich the debate; *Chapter 2* focuses on this question. Working time is an issue favored by both degrowth and a-growth, since it draws attention to a forgotten aspect of our well-being. A reduction in working time may enhance happiness, by allowing more leisure time for family, friends and people's own interests (Gorz, 1982; Pouwels et al., 2008; Latouche, 2010). However, productivity improves at the same time, which puts heavier pressure on the environment; the net impact is uncertain, and therefore quantitative research in this area is necessary if we are to draw any conclusions. *Chapters 4, 5* and *6* of this thesis focus on this issue and offer a relevant discussion.

Based on the above, and following van den Bergh (2011), **Table 1-1** summarizes the discussion by means of a tentative comparison, based on my personal estimation of the effectiveness of the five sustainability strategies (namely, growth, planetary boundaries, green growth, a-growth and de-growth) along three criteria relating to economic, political and environmental aspects. Except for de-growth, all other four strategies have a good performance in economic efficiency; growth and green growth score best in political feasibility, as voters expect benefits from growth and thus politicians are encouraged to set high growth aims; planetary boundaries, a-growth and degrowth could contribute to environmental improvement by setting specific safety margins, promoting environmental regulation and mitigating detrimental environmental impacts from economic activity.

Table 1-1. Comparison of the five sustainability strategies.

Strategies	Economic efficiency	Political feasibility	Environmental effectiveness
Growth	+ Growth can enhance well-being for certain groups, but the growing gap between rich and poor may reduce overall well-being.	++ Politicians need growth to attract votes.	−/+ Growth definitely degrades the environment, while low-carbon technologies can be stimulated based on growth.
Planetary boundary	+ Boundaries safeguard human well-being, and an improved environment also ensures a sustainable development.	? Still confined to academia and far away from political discussion.	+ Planetary boundaries provide safety zones for the environment.
Green growth	+ Supports economic growth, while the economy should be "green".	++ Meets people's requirements in regard to the economy and the environment.	−/+ Claims to promote economic growth and environmental sustainability simultaneously, but scholars doubt its feasibility
A-growth	? No enough information as GDP is not taken into account.	−/+ Difficult to get the political support, as GDP growth is still one of the primary targets of governments.	+ Indifference towards growth helps increase the support for environmental regulations.
De-growth	−/+ Zero or negative growth may reduce individual well-being, but income gap is also reduced.	− People unlikely to vote for a politician who reduces their income under current political circumstances.	+ A reduction in economic activity is good for the environment.

Note: "+" denotes a positive and "–" a negative judgment, all in relative terms, on a scale {−−, −, −/+, +, ++}.

1.2 Contribution of this research

In the context of the debate on growth and the environment as outlined above, I offer here a discussion of certain processes for achieving decarbonization and dematerialization through changes in the scale of economic activity and the amount of working time. In this thesis, I do not only empirically examine whether and to what extent working time reduction (WTR) policies or economic downscaling contribute to alleviating ecological degradation, but I also examine their underlying reasons and reaction mechanisms. By doing so, a more precise and multi-dimensional road map to achieving prosperity without growth can emerge.

1.2.1. Involuntary processes: economic recession

Currently, economic activity relies heavily on material flows (Fishman et al., 2014; Schaffartzik et al., 2014); the consumption of materials, especially of fossil fuels, is responsible for the lion's share of carbon emissions (Parker et al. 2011). As a result, there are intuitively strong correlations between economic growth (measured by GDP), on the one hand, and material use and CO_2 emissions, on the other. The reduction in material use and CO_2 emissions that take place under recessions (Bowen et al., 2009; Krausmann et al., 2009), merits attention. In this section, I review the relevant literature and I discuss whether and in what conditions dematerialization and decarbonization can be realized in times of recession.

1.2.1.1 Carbon emissions

Periods of economic recession—a term that generally describes a decline in economic activity, particularly linked to zero or negative growth—have historically been accompanied by sharp declines in CO_2 emissions (Bowen et al., 2009; Obani and Gupta, 2015). A good case in point is the 2008 economic downturn. Carbon emissions for EU-27 reduced nearly 7 percent in 2009 compared 2008 (EEA 2011). For Canada, absolute de-carbonization was realized between 2007 and 2009, during which GHG emissions dropped from 761 Mt (million tons) to 699 Mt (Young 2015). The US Environmental Protection Agency (EPA) also reported a 6% emissions decline in 2009 (total GHG emissions were 0.42 billion metric tons decline from 2008 to 2009). Even compared to environmental policies such as the EU Emissions Trading System (EU ETS), economic decline contributes more to emissions reduction (Bel & Joseph 2014).

A study published in *Nature Communications* by researchers at the University of Maryland suggests that the economic recession was a bigger driver in the decline of CO_2 emissions in the US compared to the introduction of new fracking technologies or lower gas prices, which promoted decreased coal consumption (McDermott 2012). Under this context, a further question that remains to be explored is how many carbon emissions are saved or avoided in times of recession, as this could shed light on the impact of macroeconomic events in meeting emission mitigation targets. Scenario analysis has revealed that a "degrowth" scenario could reduce more carbon emissions compare to the "business as usual" and "low/no growth" scenarios (Victor, 2012). A report estimated that, if recessions in the US had not occurred since 1950, emissions from fossil fuel use would be about 50% higher in 2007 (see **Fig.1-2**); if periods of low global GDP growth per capita (<1% per year) had not occurred since 1950, global carbon emissions from fossil fuel use would be about 50% higher as well (see **Fig.1-3**) (Bowen et al. 2009). Another estimation in relation to the European power sector during the 2008–09 recession found that emissions are reduced by 150 Mt as a consequence of the recession, out of which lower electricity demand accounts for an emissions reduction of about 175 Mt; lower carbon price resulted in an increase by about 30 Mt; and lower fuel prices contributed to 17 Mt of decrease in carbon emissions (Declercq et al. 2011).

Most researchers intuitively believe that carbon emissions move together with GDP as economic activity expands and contracts; however, this needs empirical confirmation through systematic studies in a comprehensive panel of countries. Under this context, scholars generally have revealed four facts. First, emissions are procyclical. This means that it is possible to track emissions and find out the potential drivers, thus maintaining emissions under a safety threshold. Second, procyclicality of emissions is positively correlated with GDP per capita, and specifically emissions and GDP in rich countries are coupled relatively more tightly than in poor countries (Doda 2014). Third, emissions are cyclically more volatile than GDP in a typical country (Doda 2014). Lastly, cyclical volatility of emissions is negatively correlated with GDP per capita.

A notable phenomenon is the rebound of emissions after recessions, as a quick rebound presents challenges for global carbon mitigation. Recent data on the main world economies indicate this trend. As the economy recovered, Canada witnessed a steady growth of carbon emissions, from 707 Mt in 2010 to 726 Mt in 2013 (Young 2015); Japan also experienced an increase in carbon emissions, from 1142 Mt to 1276 Mt in the period from 2009 to 2012 (GCA 2016). To develop our understanding in this area, it is important to investigate how many emissions are avoided due to a recession in a given country sample and period of time; the prevention of CO_2 emissions indicates the feasibility of de-carbonization under non-growth or low-growth scenarios, an essential issue in the degrowth arena (Latouche, 2010; Kallis, 2011; Kallis et al., 2012).

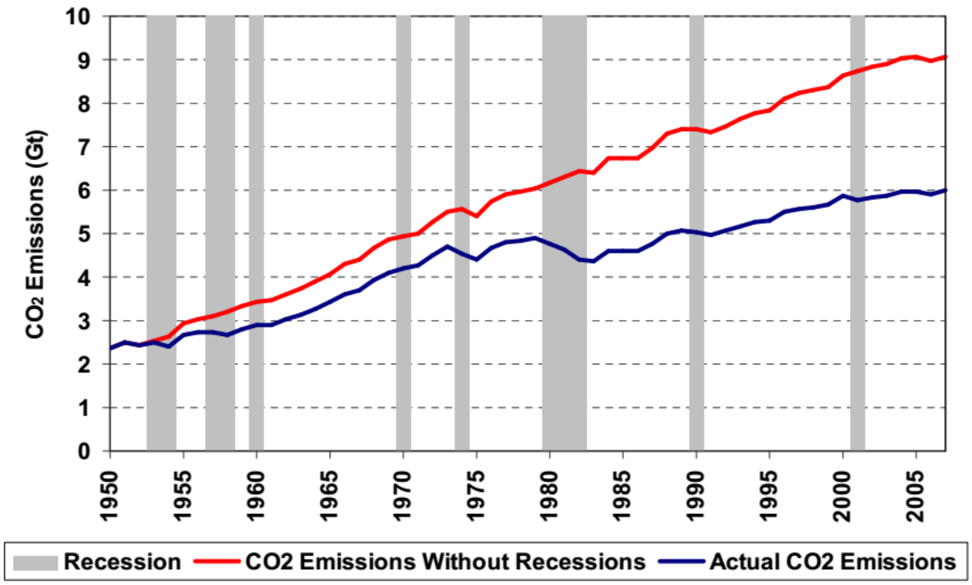


Fig.1-2. Fossil fuel CO_2 emissions in the USA for the period 1950–2007 (blue line), in comparison with the estimated fossil fuel CO_2 emissions if post-1950 recessions had not occurred (red line)

Source: Bowen et al. (2009)

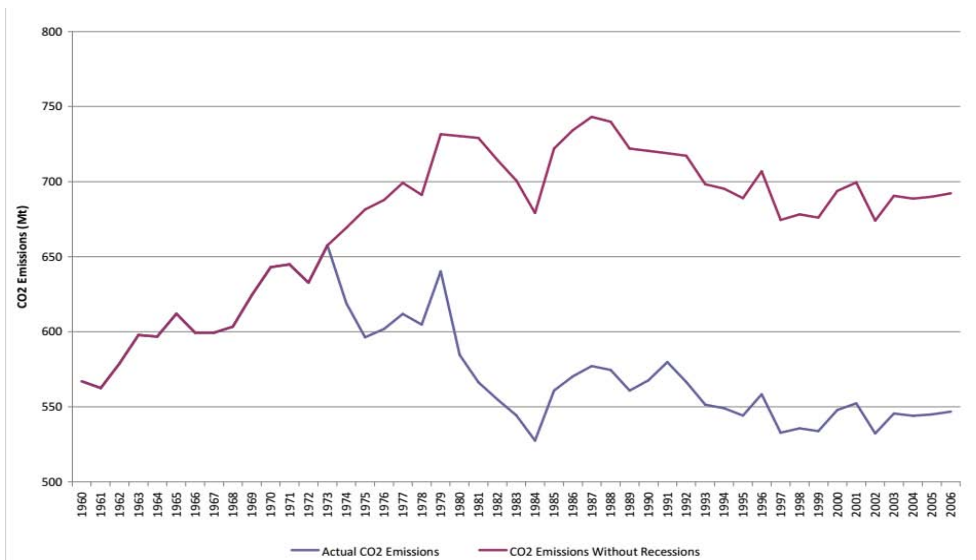


Fig.1-3. Fossil fuel CO_2 emissions in the UK for the period 1960–2006 (blue line), in comparison with the estimated fossil fuel CO_2 emissions if post-1970 recessions had not occurred (red line)

Source: Bowen et al. (2009)

1.2.1.2 Material use

In the face of global climate change, the reduction in the consumption of finite energy resources and material stock is a crucial research topic both in the academic and the political arena, partly because the extraction of resources in an unprecedented pace and scale since the First Industrial Revolution has resulted in severe pollution. Therefore, abating resource use and disengaging from economic growth are not only necessary but also obligatory for a sustainable long-term prosperity. Under this context, the concept of "dematerialization", which refers to "the real change of material and energy use in an observation year if that is less than the trend based on the levels of a given base year, and if this process occurred throughout the whole observation period" (Sun & Meristo 1999, p.277), has attracted attention. Dematerialization is both an absolute and a relative concept. This idea is similar to "decoupling", a concept used interchangeably with dematerialization in numerous publications, puzzling the readers; thus a comparison is necessary here. According to relevant literature, the two terms share the same function of measuring resource use, and both have relative and absolute states.

Their differences can be summarized in three points. First, they have a different focus. Dematerialization puts emphasis on resource use and waste generation, whereas decoupling analysis has economic variables as its focal point. Second, dematerialization has no direct link with economic performance; a lot of analysis only focuses on material use, with economic variables not included. By contrast, economic performance is an indispensable ingredient in decoupling analysis; its emphasis lies in relative changes in the relationship between economic variables and natural resource use [exceptions are Enevoldsen et al. (2007); Steinberger & Roberts (2010)]. Lastly, relative decoupling and relative dematerialization have similar connotations as they both involve comparisons between environmental pressures and economic variables. Specifically, absolute decoupling includes a precondition of economic growth and thus contains a value judgment; whereas absolute dematerialization merely focuses on the actual resource use change, without any value judgments (Browne et al. 2011). For instance, an economic recession may lead to a decrease in the actual level of both resource use and GDP; this case would be described as absolute dematerialization rather than absolute decoupling, as the latter comprises the desire for a continuous GDP growth rather than a reduced one.

In practice, energy policies, including legislation, incentives to investment, taxation, etc., are the main instruments to support dematerialization. Empirical evidence shows that policies that promote relative dematerialization have been successful only to a certain extent, although absolute levels of dematerialization remain unrealized, and many challenges persist. Fossil fuel subsidies represent one of the biggest challenges to dematerialization, as they drive down energy prices, and thus increase consumption and exacerbate environmental pressures. Yet, subsidies are still commonplace and considerably large in many countries. In 2011, Iran had the highest level of subsidies, $82 billion, whereas the overall global financial support for renewable energy amounted to a mere $88 billion in the same year, less than one-fifth of worldwide subsidies (IEA 2012). To combat this situation, measures were implemented at an international level to phase out inefficient subsidies (IMF 2013).

According to related literature, material use always grows in concert with the economy, and dematerialization may occur in periods of recession (Ausubel & Waggoner 2008; Krausmann et al., 2009; Schaffartzik et al., 2014). In 1900, the quantity of new materials that entered the US economy was 161 million tons, as shown in **Fig.1-4**. Changes in material quantity are attributed to economic recessions and wars. Specifically, material consumption was reduced by about 30% following the Great Depression in 1929, although it recovered soon. A similar trend is shown in **Fig.1-5**: the material requirements of Finland also witnessed an absolute dematerialization in times of recession (Statistics Finland 2014). The same applies to small island countries; Iceland also experienced remarkable decline throughout periods of recession, such as 1966–1969 and 1982–1983 (Agnarsson 2000). In this line, we may conclude that material flows for societal use tend to decrease in times of economic decline, but whether these are coincidental or characteristic of material-economic dynamics is still uncertain; to shed light on their correlation, more quantitative work is required.

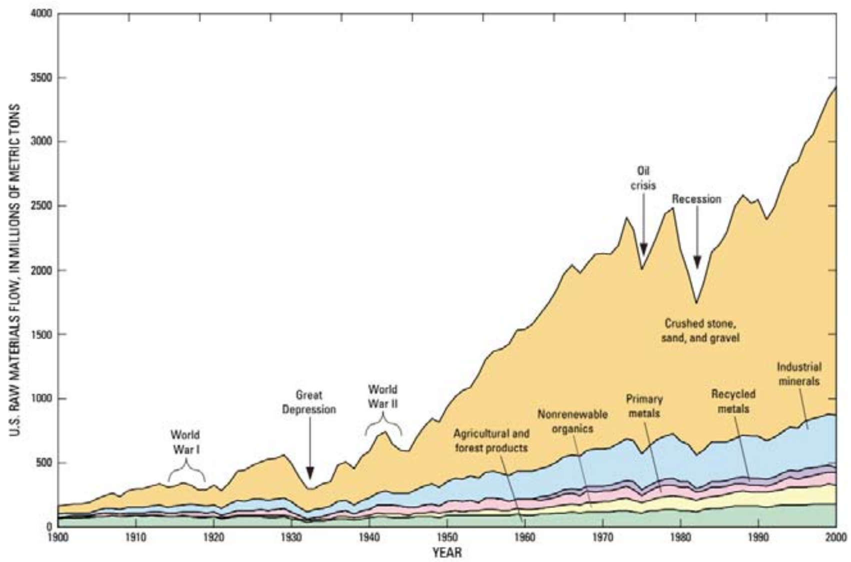


Fig.1-4. U.S. flow of raw materials by weight, 1900–98. The use of raw materials dramatically increased in the United States throughout the 20th century. Source: Wagner, (2002, p.4)

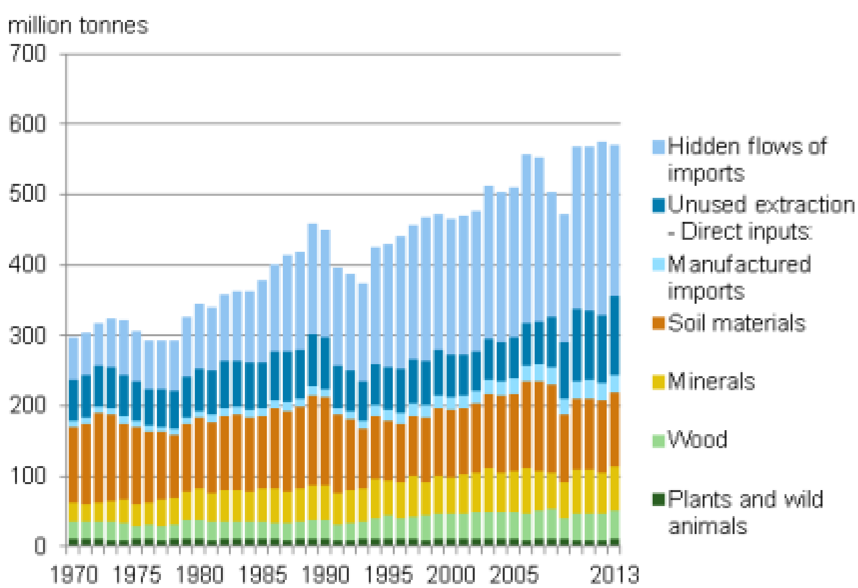


Fig.1-5. Total material requirement of Finland by material groups in 1970 to 2013

Source: Statistics Finland (2014)

1.2.2. Voluntary processes: working time reduction policy

Working time reduction (WTR) policies are another instrument in combating global climate change; these policies can increase leisure time and thus may be welcomed by labor unions. To start our analysis in this section, we will examine the concept of "work-sharing", as it represents an important measure for the reduction of working hours. Basically, this term originated in WTR policy, as work-sharing "is a labor market instrument based on the reduction of working time, which is intended to spread a reduced volume of work over the same (or a similar) number of workers in order to avoid layoffs" (Messenger & Ghosheh 2012, p.2). In doing so, available work can be shared more evenly across the population. In this light, work-sharing programs are especially necessary for economies under crisis, during which GDP declines and unemployment increases. As a rule, economic downturns are accompanied by shrinking salaries, therefore work-sharing policies are always supplemented with some type of wage subsidy, to compensate for the reduced earnings (Logeay & Schreiber 2004). This topic is beyond our scope and will not be further analyzed in the following sections.

1.2.2.1. Historical evolution

Historically, a WTR policy was first introduced in Britain, *The Factory Act of 1847*, also known as *the Ten Hours Act*. Later, in 1891, Germany implemented the *Workers Protection Act of 1891* towards the establishment of a "State Socialism". Henry Ford, the founder of the Ford Motor Company, first instituted a five-day 40-hour week in 1926, to increase productivity. Yet, massive implementation of such policies at country level dates back to the Great Depression (Rothbard, 2000; 2009), during which work-sharing programs became an effective tool in combating unemployment (Messenger & Ghosheh 2012).

During the prosperous period following World War II, with the exception of certain European countries, work-sharing schemes gradually vanished as booming economies were able to support near full or even full employment. They re-emerged as a major policy measure only after the oil crisis broke out. Thus, we could conclude that WTR policies tend to expand in times of crisis and shrink during economic booms. Unsurprisingly, during the latest great recession, which started in 2008, we have again witnessed a dramatic spread of WTR as a labor policy measure aimed at reducing unemployment (Messenger & Ghosheh 2013). According to the Office for National Statistics, more than 250,000 more people in the UK were being forced to work four days a week or less due to the 2008–09 recession, a fact that demonstrates that employers prefer to shorten their staff's hours of work in order to reduce costs rather than to lay them off. For instance, BT offered its employees a holiday if they agreed to reduce their salaries. British Airways, Ford, Honda and JCB asked their employees to reduce their working time, and the accountancy firm KPMG offered to staff a four-day week, with 86% signing up (Wallop & Butterworth 2009).

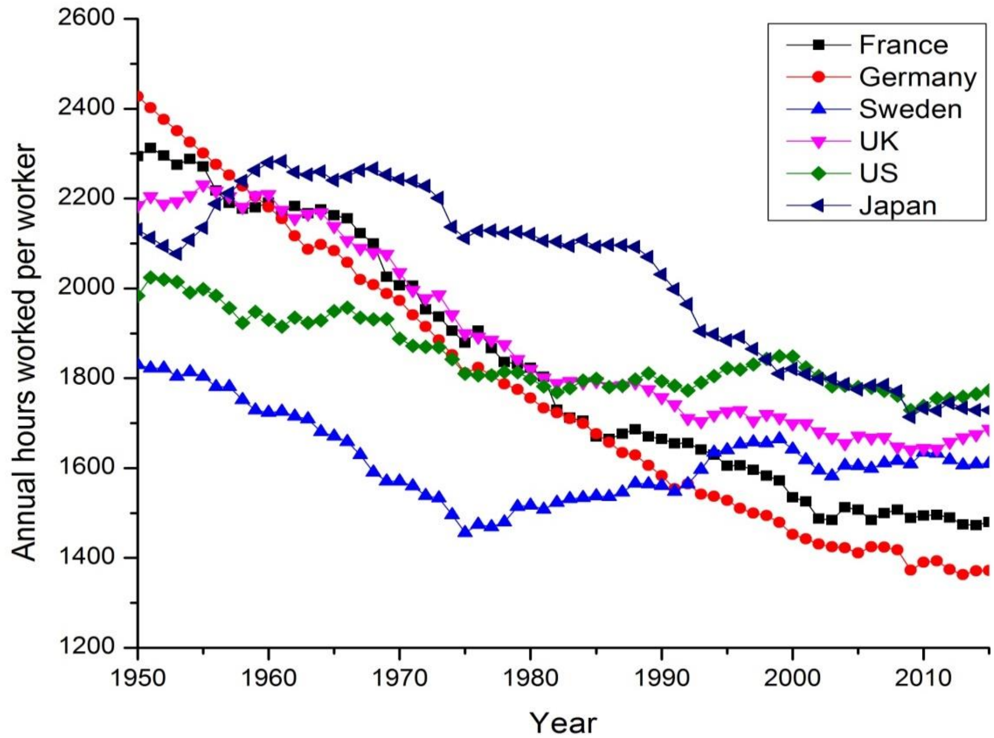


Fig.1-6. Annual hours worked per worker for selected countries, 1950-2015

Source: TCB (2016)

Fig.1-6 illustrates the annual hours worked per worker for six typical advanced economies in the period from 1950 to 2015. It shows that, in 1950, working time in Germany exceeds that of all other countries, however, it remarkably drops during the following six or so decades and is among the lowest after 1992. Japan witnessed an increase in working time in the 1950s and early 1960s, and peaked in 1961 with 2,283 annual hours worked per worker. Working time in France maintained a steady decline throughout the whole research period, while the UK and the US both touch the bottom in 2009 and rebound afterward, reaching 1,641 and 1,729 annual hours per worker respectively. This rebound may have its roots in the crisis, since a difficult economic situation may have pushed people back to work or obliged them to work longer.

Historical experience shows that WTR policies are usually designed as a tool for combating economic downturns, as they expand in times of crises and shrink when the economy improves. They are not abandoned during booming periods, but they are regarded as a part of the welfare regime. Working hours, however, do not necessarily decrease in recession periods; as a case in point, hours of work in the UK and the US increased during the crisis (see **Fig.1-6**). In addition, working hours are usually fewer in developed economies than in their developing counterparts, as "the ability to reduce working hours is a quality of advanced economies and a sign of progress, not the reverse" (Kallis et al. 2013, p.1551).

1.2.2.2. Empirical evidence

Numerous countries, especially developed ones, have successfully implemented WTR policies under various forms. The one enacted in France at the turn of the millennium attracted much attention: after the year 2000 for large firms and 2002 for small ones, working time shortened from 39 to 35 hours. Scholars have evaluated the policy effects, but their conclusions were far from unanimous. Some argue that, at the very least, the target of mitigating unemployment has been met, through a reduction in firm-level costs in combination with social security schemes in favor of unemployed workers (Logeay & Schreiber 2004); opponents insist that, despite the short-run employment effects, the policy has failed to create more jobs due to increased labor costs (Estevão & Sá 2008). Despite the debates, in most cases, WTR policies receive wide support, especially from the workers, as shorter working week allow more leisure time, which can be spent in doing sports, staying with the family, finding another part-time job, or simply practicing their interests. Most importantly, their income decreases only slightly (Reid 1982).

WTR schemes were commonly used in the Republic of Korea, where the government actively promoted assistance measures for specific industries in order to improve industrial relations and prevent the rise of unemployment. Japan has promoted a national WTR scheme operated at firm level, by providing both strong normative encouragement and financial incentives. However, despite their intuitive appeal, WTR programs have not been widely practiced in the US (Hassett & Strain 2014). Income reduction across the workforce may lead to a brain drain, especially in the case of the most qualified employees, who can easily find a new job at another firm.

1.2.2.3. WTR policies and environmental pressure

WTR policies could reduce unemployment at periods of low- or non-growth; a more balanced work and leisure hours could bring about other positive side-effects, such as the improve of well-being and reduced environmental pressures. Thus, unemployment, well-being and environmental pressure are the three main elements of WTR policies. In this section I discuss the effect of WTR policies on environmental pressure, as this aspect is the focal point of the thesis.

Regardless of its impact on the labor market and well-being, working time is closely linked to the environment, based on the $I = PAT$ equation. In purpose of examining the correlation between working hours and environmental degradation, many sets of empirical evidence have been analyzed under various research frameworks, such as scenario analysis (Rosnick & Weisbrot 2006; Rosnick 2013; King & van den Bergh 2017) and multivariate regression analysis (Schor 2005; Knight et al. 2013). There are studies that focus on just one country, such as Germany, France or Sweden (Spangenberg & Lorek 2002; Devetter & Rousseau 2011; Nässén & Larsson 2015); some focus on OECD countries (Schor, 2005; Knight et al., 2013); while some employ cross-country samples that include developed and developing countries in terms of income (Rosnick, 2013; Fitzgerald et al., 2015). Yet, despite the multiple flexible research designs, almost all studies reach similar conclusions: the environment can be improved by decreasing hours of work, regardless of the varying elasticities and significant levels. However, things may develop in the opposite direction when they become extreme. Less working time is not necessarily better for the environment. **Fig.1-7** illustrates four countries where working time generally decreased during the research period; however, total carbon emissions, the most representative environmental indicator, increased for most of the research period, excluding the period of financial crisis that began in 2007. This phenomenon indicates a “rebound” of environmental burdens due to reduced working time. Generally, previous researchers assumed that leisure time is less carbon-intensive than working time, because people tend to do activities that have a minor impact on the environment, such as spending time with family and relatives, doing sports, or just having a rest. Yet, this is not always the case, as when people are able to afford them, certain leisure activities, such as vacationing abroad, could be more carbon-intensive. (Druckman et al. 2012). Thus, the overall effect of WTR on the environment is uncertain, and income plays an essential role in this process. As Nørgård (2013, p.67) argues, “more leisure time does not guarantee a lower environmental impact…the extra leisure time will tend to require more energy, but the amount will depend on how leisure is spent”. In this light, further empirical research is necessary to determine whether and how much the environment may deteriorate due to working time reduction.

Fig.1-8 presents the overall framework of this research project: recession is one main driver of working time reduction (Messenger, 2009; Messenger & Ghosheh 2013), and both recession (i.e., GDP decline) and WTR policies (which include three elements: employment, well-being and the environment) may, or may not, contribute to environmental improvement, represented by carbon emissions and material use. In this thesis, I quantitatively analyze these relations.

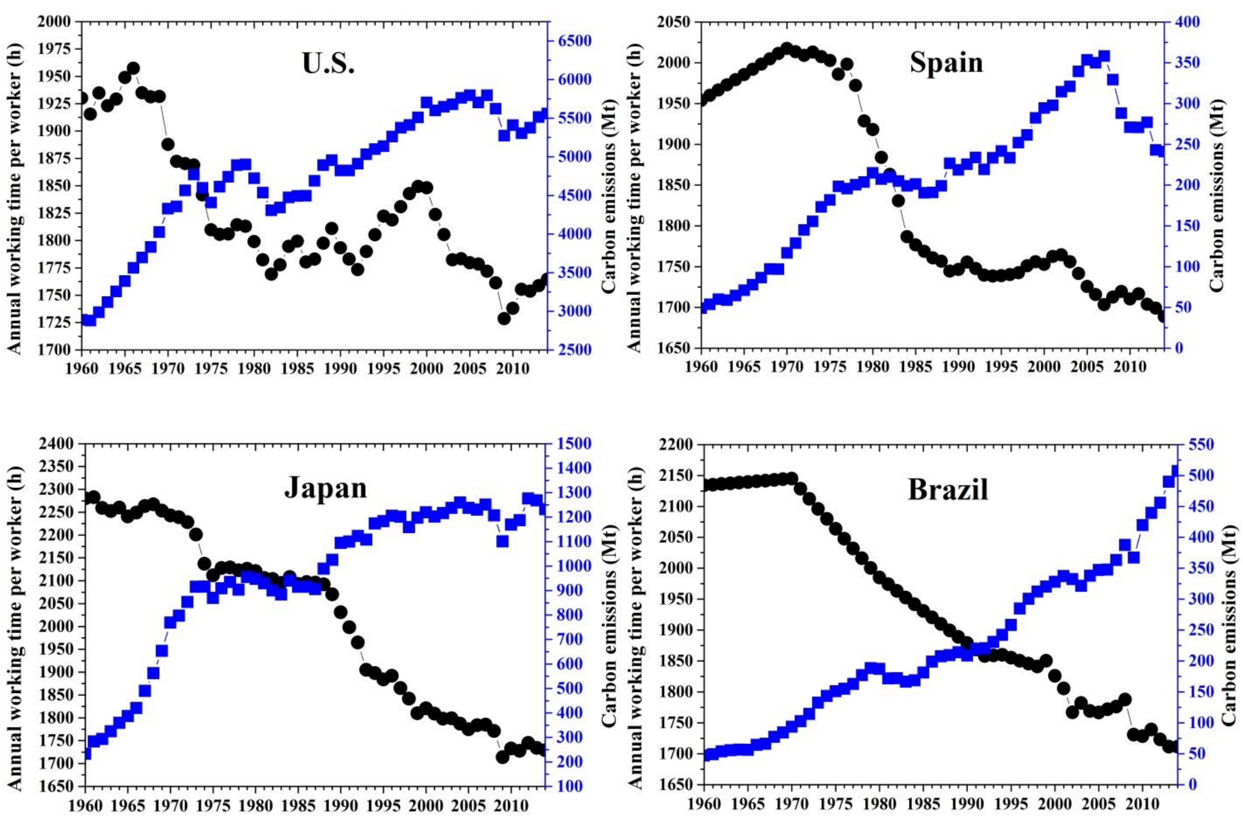


Fig.1-7. Work time and carbon emissions for the U.S., Spain, Japan and Brazil, 1960-2014.

Sources: World Bank (2016), TCB (2016) and GCA (2016)

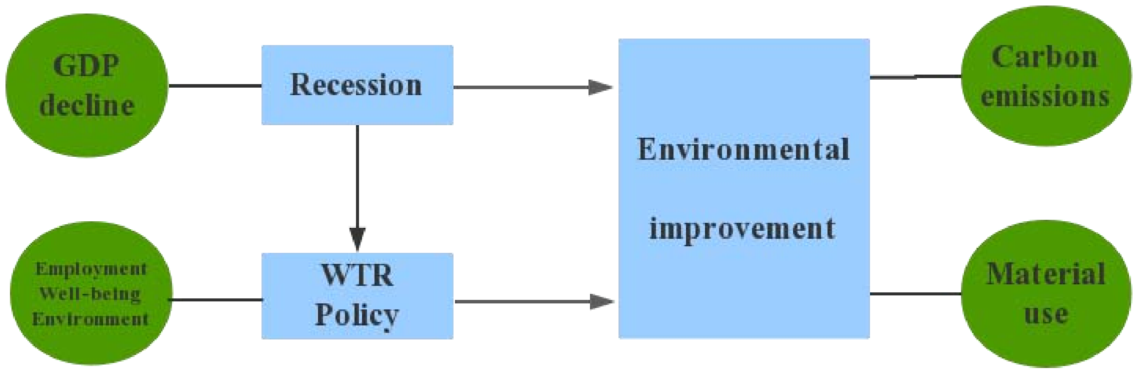


Fig.1-8. The general research framework of this thesis.

1.2.3. Research questions

The broader aim of this interdisciplinary research is to ask how and to what extent environmental burdens (i.e., CO_2 emissions and material flows in our analysis) may be alleviated by voluntary reductions in the hours of work or by involuntary contractions of the economy. We attempt to answer this question based on five separate empirical studies; two of them relate to economic recession and the other three concentrate on working time.

In particular, the first two empirical chapters (*Chapters 2 and 3*) focus on the involuntary effect of economic recessions on the environment. In *Chapter 2* I construct several models to approximately calculate how many carbon emissions are saved due to recession. The empirical result can provide an intuitive understanding of the importance of temporary economic declines, and thus illustrate the role of recessions in achieving the carbon mitigation target. After that, I investigate whether recession is the most important driver of CO_2 emissions, compared to other determinants such as renewable energy and oil price.

In *Chapter* 3, to determine how resource use, particularly domestic material consumption, varies along with economic fluctuation, I examine whether periods of recession tend to coincide with dematerialization. Additionally, as dematerialization also appears during times of low growth (Krausmann et al. 2008), I inquire into how the material-growth nexus changes with increased economic growth rate. To reach my research aim, I divide DMC into four types, that is, biomass, fossil fuels, minerals and ore, and I attempt to determine which types are more strongly affected by economic decline.

The following three empirical chapters (*Chapters 4, 5 and 6*) focus on climate mitigation through the voluntary instrument of working time reduction. Based on previous research, I first attempt to determine whether reduced hours of work have alleviated the environmental burden in advanced economies. I approach this problem based on two dimensions: on the one hand, I treat CO_2 emissions and energy consumption as dependent variables separately; on the other hand, I make the regressions by splitting the time series into two phases (1970–1990 and 1990–2010). Even though generally the correlations are significant at various levels (1%, 5% or 10%) for all three country groups (Northern, Western and Southern European countries), somewhat surprisingly, working time in Northern European countries has almost no relation to environmental pressure, and the significant correlation in the Western European country group even turns negative. To have a better understanding of this phenomenon, I try to include developing economies in the sample; I then examine whether the significant relation persists for both the developing and developed country groups, and in what conditions the negative relationship appears. If a "rebound effect" is confirmed, then the following question I should ask is at what stage do carbon emissions cease to decrease and begin to increase? These are especially important questions and have great policy implications, as through this estimate I can identify the specific countries where WTR policies are already producing a negative environmental impact, as well as those that still have the potential to alleviate their environmental burden through a shorter working week. **Table 1-2 summarizes the research questions of this research**.

Table 1-2. Research questions and corresponding study focus, methods, data and output.

Research Questions	Study Focus	Method	Main Data	Output
How many carbon emissions are saved due to recession? Is economic recession an important factor for carbon mitigation?	A rough calculation of the avoided carbon emissions; An examination of the role of economic recession in carbon mitigation, compared to other potential drivers such as renewable energy and oil price.	Counterfactual analysis; sys-GMM multivariate analysis	CO_2 emissions as dependent variables; Independent variables include GDP, renewable energy and oil price, etc. 153 economies between 1960–2014.	Chapter 2 *Q. Shao, G. Kallis*, L. D. Serrano, D. O'Neill. Nature Climate Change* (In progress)
Does economic recession have a significant effect on material use? How about low- growth conditions?	Country- and world-level case studies of dematerialization; In what conditions periods of recession and low growth coincide with dematerialization; Correlations of the four types of material use and recession/low-growth conditions.	Case study; sys-GMM multivariate analysis	Domestic material consumptions, as well as its four categories, are dependent variables; Recession dummy variable; 150 economies span from 1970 to 2010.	Chapter 3 *Q. Shao*, A. Schaffartzik, A. Mayer, F. Krausmann. Journal of Cleaner Production* (Revised and resubmitted)
What is the relationship between working time and carbon emissions for EU-15 countries?	What the working time-emissions nexus would be in the following conditions: 1) Divide into Northern, Western and Southern Europe; 2) Setting CO_2 emissions and energy consumption as dependent variables .	sys-GMM multivariate analysis	Dependent variables are CO_2 emissions and energy consumption; Annual working time per worker for EU-15, 1970–2010.	Chapter 4 *Q. Shao*. Chinese Journal of Population Resources and Environment, 13(3), 231–239.*
Considering both developed and developing economies, does a decrease in working time reduce the environmental pressure in all cases? If not, what are the underlying reasons?	The difference of the working time-emissions nexus for developed and developing economies in terms of income; The difference of the correlation before and after the year 2000 (Period 1 and Period 2); The explanations of the “rebound effect”.	sys-GMM multivariate analysis	CO_2 emissions are dependent variable; annual working time per worker for 55 economies (37 developed and 18 developing), 1980–2010.	Chapter 5 *Q. Shao*, B. Rodríguez-Labajos , Journal of Cleaner Production， 125 (2016), 227–235.*
If shorter hours of work may cause an energy rebound, then when does a reduction in working time harm the environment? Which countries do already show signs of this?	We estimate threshold values, divide into different regimes and compare the correlations within each regime; then we identify the countries that demonstrate a negative impact on the environment with reduced working hours.	Panel threshold model	CO_2 emissions and energy consumption as environmental indicators; Working time and GDP per capita as threshold variables. EU-15, 1970–2010.	Chapter 6 *Q. Shao*, S. Shen. Journal of Cleaner Production, 147(2017), 319–329.*

1.3 Methodology and data

1.3.1 Methodology

In this thesis, the quantitative method that will be used to perform empirical analyses of the correlation between working time and environmental pressure, on the one hand, and the effect of economic recession on environmental indicators (CO_2 emissions and domestic material consumption), on the other, is the *system Generalized Method of Moments (sys-GMM),* an advanced dynamic panel data analysis. This section explains the method used for data collection and quantitative analysis.

The primary aim of econometric analysis is to "estimate the effect of several independent variables on a dependent variable" (Bachman & Paternoster 1997, p.490). As for panel data, which are usually generated when a large number of individuals, firms or countries are observed for a certain amount of time, there are numerous ways to proceed. This means that panel data involves two dimensions: a cross-sectional dimension N and a time series dimension T. Panel data usually require a large number of values, thus "increasing the degrees of freedom and reducing the collinearity among explanatory variables – hence improving the efficiency of econometric estimates" (Hsiao 2003, p.3).

"[E]conomic behavior is inherently dynamic so that most econometrically interesting relationships are explicitly or implicitly dynamic" (Nerlove 2002, p.xiii). Given the dynamic nature of many economic relationships (Baltagi 2005, p.135), especially that between CO_2 emissions and material flows in our empirical analysis, we employ dynamic panel models in my analysis (Dang et al., 2012; Müller 2006; Felbermayr 2005). Compared to static models, a lagged dependent variable is presented among the regressors, i.e.,

$$y_{i,t} = \alpha y_{i,t-1} + \beta x_{i,t} + \mu_{i,t} \qquad i = 1,....,N; t = 1,....,T \qquad (1)$$

Where α is a scalar, $x_{i,t}$ is $1 \times K$ and β is $K \times 1$, $\mu_{i,t}$ is the error term. For the endogeneity of the model, instrumental variables are employed in GMM; these variables are represented by lagged observations of the explanatory variables, thus labeled "internal" instruments; autocorrelation and individual effects can be wiped out by the first difference transformation. In this line, we can easily tackle the correlation problems (Baltagi 2005). For example, to remove the error term, the model can be first differenced and then employing $\Delta y_{i,t-2} = (y_{i,t-2} - y_{i,t-3})$ as an instrumental variable for $\Delta y_{i,t-1} = (y_{i,t-1} - y_{i,t-2})$.

The two GMM approaches are *diff-GMM* and *sys-GMM*, which are short for difference GMM and system GMM. The former uses lagged level observations as instruments for differenced variables; the latter utilizes both lagged level observations as instruments for differenced variables and lagged differenced observations as instruments for level variables. In other words, sys-GMM is an improved method based on diff-GMM, and the estimator includes lagged levels as well as lagged differences. Thus, considering these drawbacks of diff-GMM, I choose the sys-GMM approach to be the main research method in this thesis. In the regressions, to make the result more reliable, autocorrelation would be tested by AR(1) and AR(2), that is an autoregressive process of order one and a second-order autoregressive process; validity of instrumental variables would be tested by the Sargan p-value.

Additionally, in *Chapter 6* we introduce a new method named *panel threshold model* to examine correlations between working hours and environmental pressure. This method has always been used in macroeconomic and financial analyses; as far as I know, it is the first time this econometric tool is introduced in environmental studies. It is best characterized as a method to examine the *non-linear* relationship between two or more variables, thus it is closer to reality (see **Fig.1-7**) and could produce more meaningful results. Generally, there are three steps in the model: First, threshold values are estimated endogenously, which can prevent imposing a priori an arbitrary classification scheme (Chang et al. 2009) and thus enhances the credibility of the results. Second, these thresholds (one or multiple) are used to separate country samples into classes (or "regimes" used in this model). Third, correlations are established between the explanatory and outcome variables within each class (regime). In relation to the research background, the main aim of this method is to determine in which countries working time is too short to reduce environmental burdens. **Fig.1-9** presents the research logic of the panel threshold model: once data is inputted, we estimate n threshold values; the n threshold points result in n+1 regimes; the sample countries are then classified into those different regimes; the correlations of working time and environment in each of the n+1 regimes may also be different; finally, we compare these correlations and summarize the result.

The following example will help clarify the above. In my analysis, two threshold values are generated, and thus we obtain three regimes, so there are specifically three working time phases in the analysis. When setting working time as the threshold variable and energy consumption as the outcome variable, four countries are grouped into the low-level working time phase, ten countries are classified in the mid-level phase, and only one country remains in the high-level phase for the year 2010. **Fig.1-10** visually presents these results: two threshold values (based on working time) divide into three regimes: Regime 1 denotes a high-level working time phase, Regime 2 denotes a mid-level phase and Regime 3 a low-level phase. We can see that one, ten and four countries fall into these three regimes respectively. In the text, we find that the correlation turns from being positive at the mid-level phase to being negative at the low-level phase. In this line, we conclude that a shorter working time in those four countries is already aggravating environmental pressures. This is the major argument of my study.

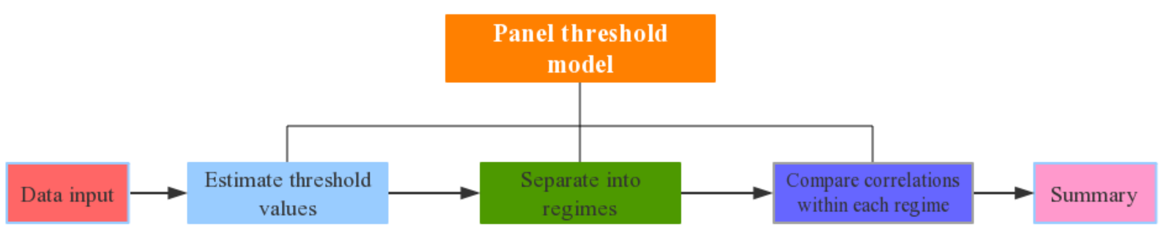


Fig. 1-9. The logic of panel threshold model

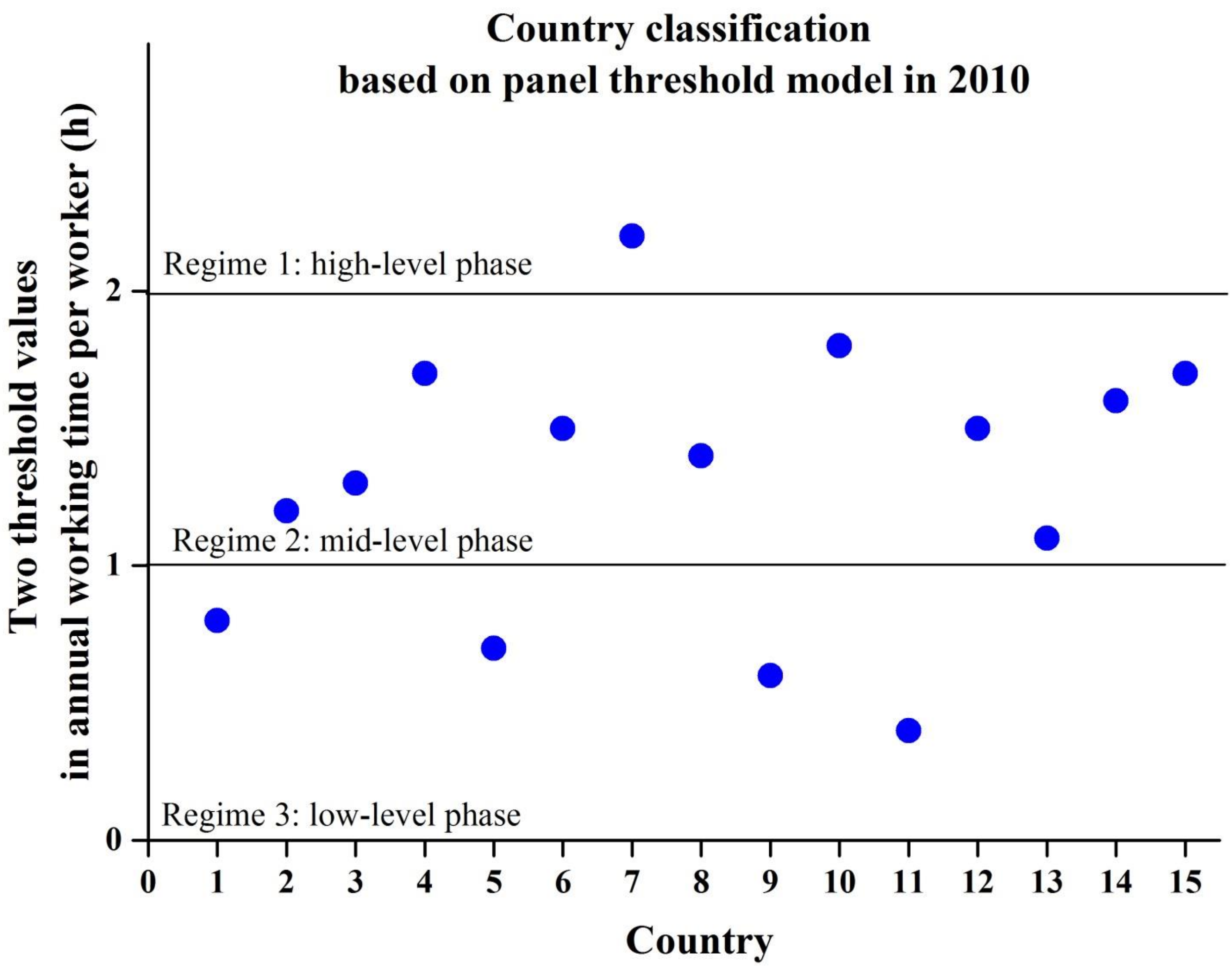


Fig. 1-10. Country classification based on the panel threshold model for the year 2010.

1.3.2 Data

Depending on the focal questions and the aims specified in each study, we mainly use quantitative techniques to collect data. Data is collected from several important and widely used databases, such as the World Development Indicators Database (World Bank 2016), OECD Statistics (OECD 2016), UNEP Environmental Data Explorer (UNEP 2016) and the Conference Board Total Economy Database (TCB 2016). Specifically, the World Bank (2016) provides the most comprehensive worldwide open data on various topics since 1960, essential indicators such as CO_2 emissions and economic recession are all extracted from this database. OECD.Stat (2016) includes data for OECD member countries as well as certain non-member economies; *Chapters*

2 and 3 employ its accurate technology data (counted in files) as important control variables. Material flow data in four categories (i.e., biomass, fossil fuels, minerals and ores) for each economy, which are essential dependent variables used in *Chapter 3* to help examine which types of material flows are significantly/insignificantly affected by recession, were extracted from UNEP (2016). Although different to World Bank (2016), TCB (2016) is also a comprehensive database with annual data for over 120 world countries, which provides thus far the most comprehensive set of data on annual working hours per employee, covering more than 50 economies since 1950; this data is an essential independent variable in working time analysis (*Chapters 4, 5 and 6*).

For the purpose of a systematic treatment for meaningful analysis, Microsoft Excel, OriginPro 9.0 and Stata 14 were used. I use Excel to organize and manipulate data. OriginPro 9.0 is a professional data analysis and graphing software, which produces clear and beautiful plots. Graphs in this thesis are mostly generated using this software. Given its powerful ability to detect causal relationships among different variables, we use Stata 14 to make regressions and econometric analysis in all empirical studies.

2. Recessions and avoided carbon emissions

2.1 Introduction

Periods of recession have historically been accompanied by sharp declines in CO_2 emissions. During the 2008-09 economic downturn emissions in EU-15 decreased by 6.9%, and in the U.S. by 6%. An input-output analysis of the U.S. economy shows that the 11% decrease in emissions from 2007 to 2013 was concentrated in the 2007-2009 period, when emissions declined by 9.9%; more than half of this decline was due to the recession (Feng et al. 2015). With the exception of 2015, all other nine years since 1970 that saw absolute declines in global carbon emissions (**Fig.2-1**) were years of global or regional economic crises with spikes in the number of countries experiencing recession (**Fig.2-2**). Recession is defined as a year with a decrease in economic output (Reddy & Minoiu 2009;, Burke et al., 2015). 1061 country-years have experienced recession since 1961 (for our dataset see Methods). 58% of these national recession years were accompanied by decline in carbon emissions. And out of 998 country-years with absolute reductions in carbon emissions, 409 were in recession years (41%).

Economists have studied the macro-economic impacts and output losses of recessions (Claessens et al. 2009) , but not their environmental or carbon emission effects. Given the exceptionally fast recovery of carbon emissions after the 2008 crisis (Peters et al. 2012), climate scientists and economists have debated whether the emissions-income elasticity, that is the percentage change in carbon emissions for a 1% change in GDP, is the same during growth and recession periods. York (2012) finds that it isn't, emissions growing faster with income during expansionary periods (York 2012a). Using a different method and including in their dataset countries with less than 500 thousand people, Burke et al (2015) find instead a symmetric elasticity of 0.5 for both recession and boom periods (but find a higher elasticity for growth periods when long-term, lagged effects are also taken into account) (Burke et al. 2015).

The effect of a recession on carbon emissions is without doubt statistically significant, but is it relevant: how big is it, how does it compare to that of other forces, and how durable is it given possible negative effects of recessions?

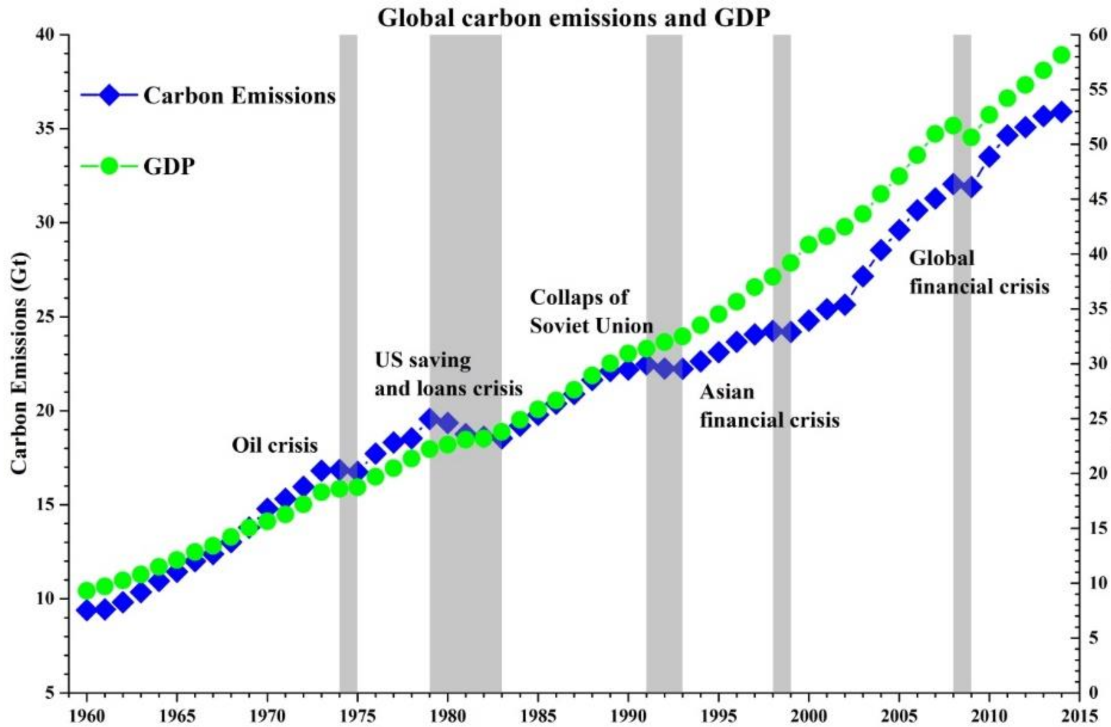


Fig.2-1. The Global Economy and Carbon Emissions. Total GDP and Carbon emissions 1960-2014.

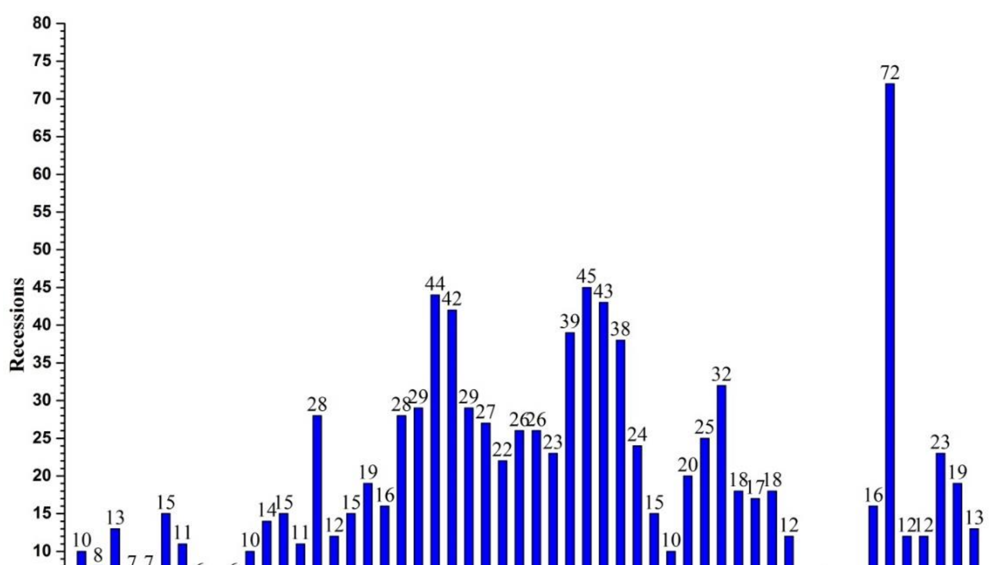


Fig.2-2. Number of countries in recession 1961-2014. Where recession is a year where GDP declined. Based on World Bank (2016) Data for 153 countries with more than 100,000 people.

2.2 Data and method

To calculate the amount of carbon emissions avoided, we follow an approach used by economists to calculate output losses during recessions. We first need a rough estimation of how many years the effects of a recession last. A panel data regression where the binary variable recession at year t is the independent variable and the % change in carbon emissions at years t-2 to t+10 the dependent, finds a statistically significant effect at the 0.05 and 0.01 levels for years t-1 to t+3 (**Table 2-4**). We then build a counterfactual model of emissions and calculate it on a country-by-country, recession-by-recession basis (Model 1), extrapolating a counterfactual t-6 to t-2 linear trend up to t+3, and then subtracting the historically observed values from years t-1 to t+3 (see the example of Spain). We do not double count subsequent years of recession within the four-year window and in the very rare cases that post-recession values are above trend we do not take them into account.

2.2.1 Data

Table 2-1 presents the main variables, definitions, units and data sources used for this research. Our sample includes 153 main economies with data from 1960 to 2014. For the research sample, we excluded countries with population lower than 100,000 (such as Antigua and Barbuda, Dominica and Greenland). The most populous countries not in our sample are the Democratic Republic of Korea (25 million), Latvia (1.98 million) and Belarus (9.51 million) due to missing CO2 emissions data. These economies account for 93.25% of world emissions and 97.87% of world GDP at 2014 and thus are representative 14,7.

According to our dataset, since 1961, there have been 1061 national recession country-years which defined as a year with a decrease in gross output following Reddy & Minoiu (2009) and Burke et al. (2015), on average 6.93 years per country, and 684 recession periods (4.47 per country on average), understood as continuous periods of one year or more with negative economic growth. Annex I countries have experienced on average 3.58 recession periods each (and 216 recession years), whereas Annex II countries 4.80 (830 recession years). The typical recession lasts one year. One-year recessions account for 68.57% of all recessions; 20.47% lasted two years, 5.99% for three years, and 4.97% for four years or more. Ukraine experienced the longest series of recessions, ten years long – from 1990 to 1999. 75.87% of national recession country years took place within a period of -1 to +3 years from one of five major global economic events.

2.2.2 Method

To calculate the amount of carbon avoided, we build a counterfactual model of emissions on a country-by-country, recession-by-recession basis (Model 1), extrapolating a counterfactual t-6 to t-2 linear trend up to t+3, and then subtracting the historically observed values from years t-1 to t+3.

To illustrate how we calculated avoided emissions, consider the 2009 recession in Spain (see **Fig. 2-3**). GDP was down -3.57% and carbon emissions -12.46%. We calculate counterfactual values by extrapolating the linear least squared fitting formula based on CO_2 emission data five years before, and calculate the carbon emissions saved 2008-2012 (one year before and three years after based on the recession year 2009). For example, the extrapolated value of CO_2 emissions in 2009 if there were no recession would be – 16675.47 + 8.49 × 2009 = 380.94 Mt. Thus, the carbon emissions avoided in 2009 are the extrapolated value minus the observed value, i.e. 380.94 – 288.24 = 92.70 Mt. Overall, the total amount of carbon not emitted by Spain due to the 2009 recession is 511.43 Mt. In the cases that recessions last more than one year, we avoided double counting. And in the very rare cases that observed values were higher than the extrapolated, we ignored these values. They are almost all small economies with minor carbon emissions, such as a recession at Albania in 1997, in Benin in 1971, in Cameroon in 1967, and in Burundi during 1968-69.

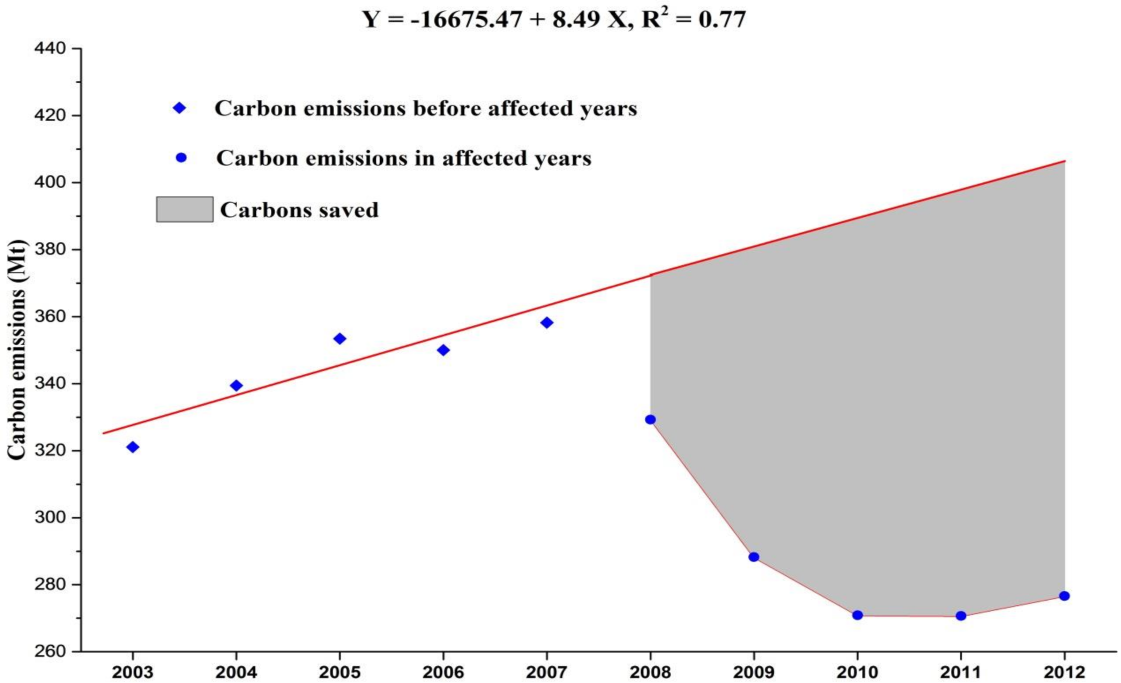


Fig 2-3. Linear extrapolation of carbon emissions in Spain from 2003 to 2012. Recession year is 2009, and the effects of recession start one year before (2008) and last three years after (2010, 2011 and 2012)**.** Shadow area denotes avoided carbon emissions.

To test the effect of GDP growth we run an estimation model using first-differenced (change from year to year) variables. The basic regression equation is:

$$\Delta LnCarbon_{i,t} = \alpha \Delta LnGDP_{i,t} + \delta \Delta LnControls_{i,t} + \mu_i + \varepsilon_{i,t} \qquad (1)$$

where Δ is the first difference operator, subscripts i, t denote the i h cross-section and t h time period. $\Delta LnCarbon_{i,t}$, the rate of change of carbon emissions from fossil fuel combustion and cement production is the dependent variable and $\Delta LnGDP_{i,t}$ the independent. μ_i denotes unobserved country-specific fixed effect remain constant over time and $\varepsilon_{i,t}$ is unobserved White-noise disturbance with $E(\varepsilon_{i,t}) = 0$ for all i and t.

$\Delta LnControls_{i,t}$ are control variables employed in the analysis. Comparison/control variables include the rate of change of oil prices (*Oil Price*), technology innovation, as measured by the number of patents three years before (*Tech Inno (t-3)*), installed renewable capacity (*Rene Capa*). We use standard data sources from international organizations like the World Bank (2016), IEA

(2016) and UNEP (2016) (**Table 2-1**) (World Bank, 2016; IEA, 2016; UNEP, 2016). We obtain similar results using alternative emissions data from IEA (2016) and GDP data from Feenstra et al. (2015). The results are presented in **Table 2-1** and the robustness checks in **Table 2-2**.

To arrive at a more precise estimation of a change in growth rates we identify different elasticities for positive and negative growth rates, following Burke et al. (2015) and York (2012) using the following basic model:

$$\Delta LnCarbon_{i,t} = \alpha \Delta LnGDP_{i,t}^{-} + \beta \Delta LnGDP_{i,t}^{+} + \delta \Delta LnControls_{i,t} + \mu_i + \varepsilon_{i,t} \qquad (2)$$

Where $\Delta LnGDP_{i,t}^{-}$ denote the GDP values during recession and $\Delta LnGDP_{i,t}^{+}$ are GDP during growth periods.

In smaller countries, small changes, such as a departure or arrival of a foreign investment or the installation of an electricity factory can make a huge, untypical difference. To filter out the distorting effect of extreme carbon and GDP growth rates that do not represent underlying dynamics (Leone et al. 2013), we trim the variables at the 1st and 99th percentiles (Gilchrist et al. 2005) and constrain our research to countries with population higher than 100,000.

To test for lagged effects and 'back-firing', we use an estimation model as follows:

$$\Delta Ln \sum_{T=t-2}^{t+10} Y_{i,T} = \alpha Recession_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t} \qquad (3)$$

Where $Y_{i,T}$ stand for the dependent variable of interest, namely carbon emissions, installed renewable capacity, renewable innovation as measured by the number of patents for renewable energies, percentage of coal in the fossil fuel mix and biomass consumption. $Recession_{i,t}$ last for ten years. γ_t denotes unobserved year-specific fixed effect remain constant across the country. All variables are logarithmized and first-differenced except for the binary variable $Recession_{i,t}$. For biomass consumption we control for agricultural production, given that we could not find data for the use of biomass for energy alone. We hence use data for total domestic biomass consumption and control for changes in agricultural production, that we assume control for variation in the use of biomass from agriculture. For results see **Tables 2-4 to 2-8**.

Table 2-1. Summary statistics

Variables	Definitions and Units	Period	Summary Statistics			Sources
			Max	**Min**	**Mean**	
Carbon emissions	CO_2 from combustion of fossil fuels and the manufacture of cement (kilotonnes)	1960-2014	2,584,538	36.67	76,906.25	World Bank (2016) GCA (2016)
GDP	Gross domestic production (Million US$, 2005 cons)	1960-2014	4,208,696	241.37	157,833.90	
Agriculture GDP	Gross domestic agriculture production (Million US$, 2005 cons)	1961-2013	452,118	31.20	10,411.10	
GDP(for robust check)	Real national prices gross domestic production (Million US$, 2005 cons)	1960-2011	4,002,790	602	188,639.80	Feenstra et al. (2015)
Carbon emissions(for robust check)	CO_2 from fuel combustion (kilotonnes)	1971-2013	4,320,398	400	111,830.90	IEA (2016)
Rene capa	Total installed capacity of renewable sources of energy (Thousand Kilowatts)	1980-2012	321,449.5	0	4,879.63	
Recession	1 if ΔLn GDP < 0, otherwise 0	1960-2014	1	0	0.1556	Base on GDP growth
Oil Price	US$ per barrel, West Texas Intermediate	1976-2014	100.06	14.22	39.16	BP (2016)
Tech Inno	Technology patent counts (files)	1976-2011	52,068.32	0	743.40	OECD (2016)
Rene Inno	Patent counts on technologies related to renewable energies (files)	1990-2011	1153.11	0	19.15	
Coal.%Fossil	Percentage of coal of fossil fuels	1980-2013	100	0	55.45	SERI (2016)
Biomass	Biomass consumption (kt)	1970-2010	3,250,108	0	81,491.35	UNEP (2016)

Note: all the data are already trimmed at 1th and 99th percentiles.

Table 2-2. Robustness check

Variables	*Dependent Variable: ΔLn Carbon Emissions*				
	(1) **All**	**(2)** **All**	**(3)** **All**	**(4)** **Annex I**	**(5)** **Annex II**
ΔLn GDP	0.5752*** (0.028)	0.6022*** (0.036)			
ΔLn GDP⁻			0.4058*** (0.064)	0.8060*** (0.111)	0.2838*** (0.082)
ΔLn GDP⁺			0.6566*** (0.057)	0.3935*** (0.098)	0.7287*** (0.073)
ΔLn Rene capa		-0.0317** (0.015)	-0.0390** (0.019)	-0.0077 (0.021)	-0.0839*** (0.032)
ΔLn Tech Inno (t-3)		-0.0069** (0.003)	-0.0062** (0.003)	-0.0088* (0.005)	-0.0049 (0.004)
ΔLn Oil Price		-0.0004 (0.006)	-0.0051 (0.006)	-0.0089 (0.008)	-0.0020 (0.010)
Constants	0.0083*** (0.002)	0.0037* (0.002)	0.0005 (0.003)	-0.0034 (0.004)	0.0094** (0.004)
R^2 (within)	0.0947	0.1280	0.1298	0.1342	0.1438
Obervations	4163	2217	1773	811	935

Notes: Carbon emissions sourced from IEA (2016) and real GDP at constant 2005 national prices data from Feenstra et al. (2015).

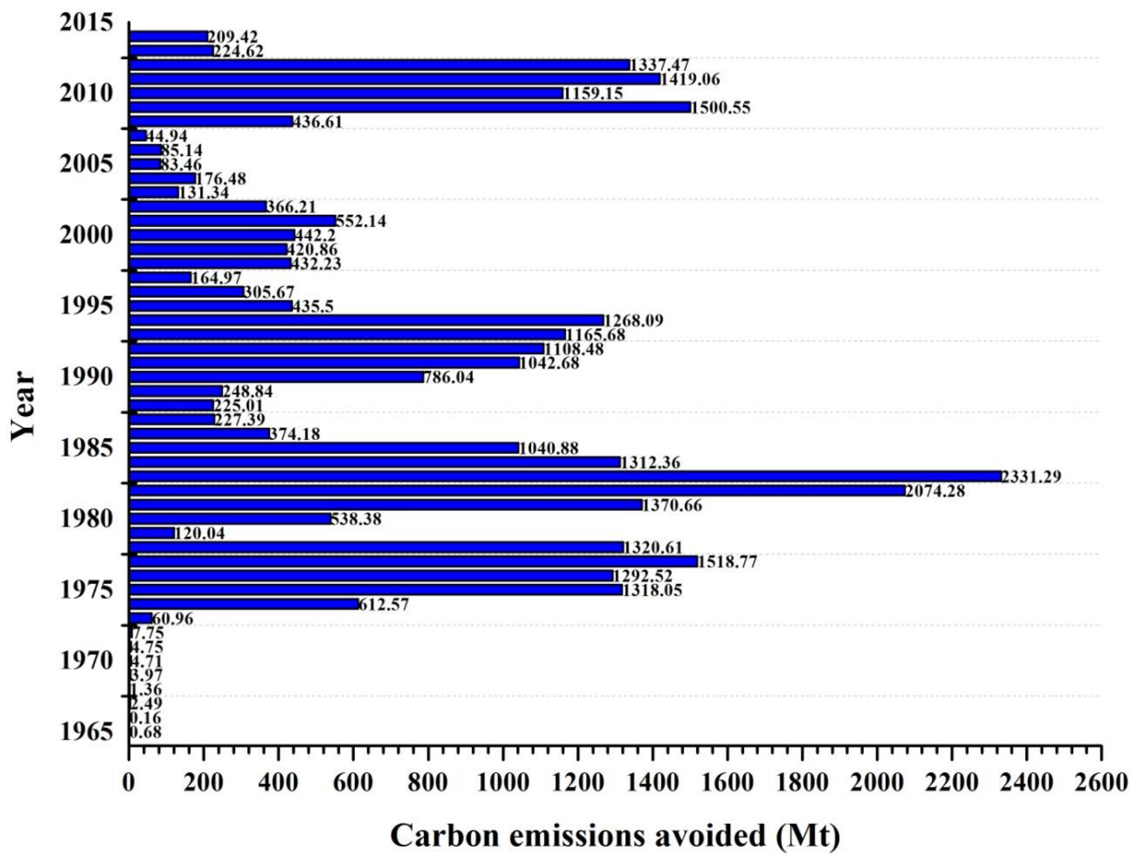
2.3 Carbon emissions avoided due to recession.

We estimate that a total of 31.34 Gt CO_2 have been avoided due to recessions since 1960, 23.79 Gt CO_2 in Annex I countries and 7.55 GtCO_2 in Annex II (Model 1). Our counterfactual is a rough approximation since it assumes first, that all declines from trend are due to recession (if there are other factors that also change in the same years and reduce emissions then our estimate is an overestimation), and second, that there aren't changes in other factors that offset this reduction (if there were, then our estimate is an underestimation). Our national-level approach misses also the avoided emissions from national contractions that do not qualify themselves as recessions but they are the effect of global recessions. For example, the 2008-2009 global recession originating in the US led to a decline of GDP growth in Poland from 3.92% in 2009 to 2.63% in 2010, emissions declining by 5.44%. To capture this effect, we calculate avoided emissions at the global level for years t-1 to t+3 and for each major global economic downturn (Model 2). Model 2 doesn't capture country recessions outside the five global crises that are captured instead in Model 1. Overall savings according to Model 2 are 38.61 Gt CO_2 suggesting a robust estimate of savings roughly close to one year of carbon emissions at their 2014 level (35.89 GtCO_2). This amounts to a 2.67 % (Model 1) to 3.28 % (Model 2) reduction of total emissions from 1960 (dividing 31.34 or 35.89 by 1175.45, the sum of annual emissions from 1960 to 2014).

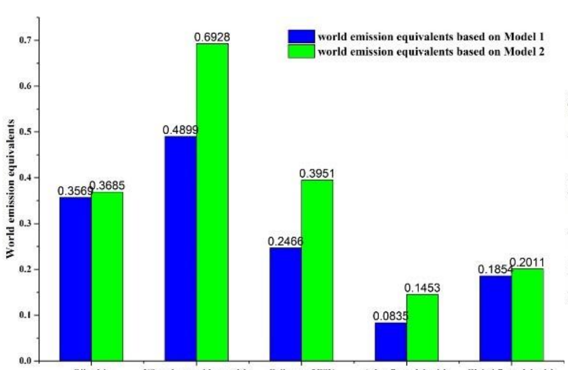
The level of avoided emissions depends on the level of total emissions the year the recession takes place. The effect of recessions is likely to be smaller in absolute terms the further back in time we go in time, as emissions were then lower. If we were to normalize the incurred savings as a fraction of the actual global carbon emissions the year that the recession started then the accumulated effect of recessions since 1960 is equivalent to 1.5 (Model 1) to 1.8 (Model 2) years of emissions.

66.7% of all country-based savings (Model 1) took place in the four-year period (-1 to +3) around the five major events of global significance (**Fig.2-3a**). Both in absolute and relative terms, most emissions were avoided in the 1979-83 'second oil' or 'US savings and loan' crisis (**Fig.2-3b**). The savings from the 2008 crisis are moderate, comparable in absolute terms to those of the 1974 oil crisis, but much smaller in relative terms. This goes along with the observation that the effects of the 2008 crisis were short-lived (Peters et al. 2012). This might be explained by the fact that unlike previous crises, most national recessions were concentrated in a single year, 2009, a much narrower distribution of recessions around the year of global recession compared to previous crises (**Fig. 2-2**). In other words, the crisis was intense, but short, hence the rebound.

a.



b.



c.

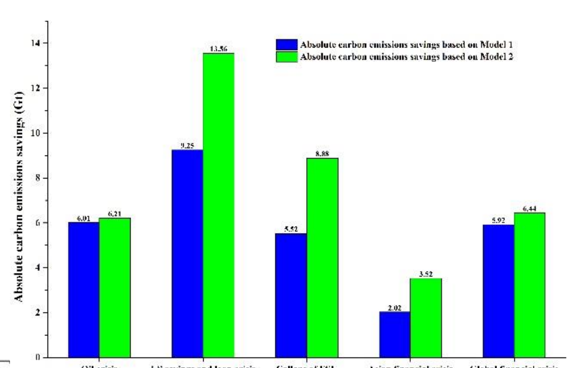


Fig.2-3. Avoided CO_2 emissions from fossil-fuel combustion and cement due to major recessions. a. Absolute savings year by year calculated by Model 1. **b.** Absolute savings for each major global

economic event, calculated country by country (Model 1) and at the global level (Model 2). **c.** Savings relative to global carbon emissions at the beginning of the global economic events, calculated country by country (Model 1) and at the global level (Model 2).

To compare the effects from recessions to other factors we run an estimation model using first-differenced (change from year to year) variables. The rate of change of carbon emissions (from fossil fuel combustion and cement) is the dependent variable. Independent variables include the rate of GDP growth, in growth (GDP^+) and recession (GDP^-) years. We compare this to the effects of the rate of change in installed renewable capacity, the rate of technological innovation, as measured by the number of patents granted, the rate of change in oil prices, and the rate of urbanization. We apply country and year fixed effects reducing the error from time-invariant factors such as climate or geography that affect the trajectory of both emissions and GDP, and from global factors that change over time but affect all countries equally, like oil prices or an international event or policy. Our regression without controls finds an emissions-income elasticity of 0.5, very close to the 0.52 of Burke et al (2015). The addition of control variables for the purpose of comparison increases the income elasticity of emissions to 0.61, close to that reported by others in the literature (refs) and contrasting Burke et al. (2015) claim that given that growth affects emissions via the energy sector controlling for renewable energies would dampen the effect of GDP (Burke et al. 2015). We confirm a symmetric effect, the elasticity for growth and recession years being almost identical at 0.59% (0.45% for Annex I and 0.62% for Annex II countries) (**Table 2-3**).

Recession is the only factor with a statistically significant (at the 0.01 level) effect on carbon emissions. The effect of a 1% decline in the growth rate is 18 times (0.6224/0.0350) that of a 1% increase in renewable capacity for all countries, and 11 times (0.6661/0.0596) for Annex II country group. The effect of technological innovation is statistically insignificant and negligible in scale. Oil price showing negative effect on carbon emissions but insignificant. To put these numbers in perspective, a mild recession, say from a minimum healthy growth rate of +2% to a recession of -2%, that is 4 decimal points loss of growth, has the equivalent effect on emissions of a 71% increase in renewable energy capacity ($4\times0.6224/0.0350$). The latter is close to the 90.88% growth in global installed renewable capacity from 822.77 in year 2004 to 1407.67 Million Kilowatts in 2012.

Table 2-3. Comparing the effects of GDP, renewables, technology and oil prices on CO_2 emissions for all countries and its sub-samples (Annex I and II) using fixed effect model.

Variables	***Dependent Variable: ΔLn Carbon Emissions***				
	(1) **All**	**(2)** **All**	**(3)** **All**	**(4)** **Annex I**	**(5)** **Annex II**
ΔLn GDP	0.5752*** (0.033)	0.6447*** (0.046)			
ΔLn GDP⁻			0.6224*** (0.047)	0.5448*** (0.071)	0.6661*** (0.063)
ΔLn GDP⁺			0.6227*** (0.047)	0.5462*** (0.071)	0.6659*** (0.063)
ΔLn Rene capa		-0.0315* (0.019)	-0.0350* (0.020)	-0.0054 (0.023)	-0.0596** (0.031)
ΔLn Tech Inno (t-3)		-0.0002 (0.004)	-0.0004 (0.004)	-0.0069 (0.005)	0.0017 (0.005)
ΔLn Oil Price		-0.0004 (0.007)	-0.0033 (0.008)	-0.0028 (0.009)	-0.0024 (0.011)
Constants	0.0158 (0.002)	0.0013 (0.002)	0.0023 (0.003)	-0.0098 (0.003)	0.0112*** (0.004)
R^2 *(within)*	0.0467	0.0851	0.0944	0.0962	0.1007
Obervations	6342	2317	2162	891	1239

Note: Robust standard errors in the parentheses; time fixed effects are not included; *, ** and *** denote significant p-value at the 10%, 5% and 1% levels, respectively.

2.4 Do recessions backfire?

We do not find evidence of backfiring. We test for lagged effects of recessions (independent binary variable) on the rate of growth of carbon emissions (dependent variable) for up to 10 years after the event (**Table 2-4**). After year t+3 there is no statistically significant correlation, positive or negative. Similarly, we do not find any effects on the rate of growth of renewable capacity or the number of patents granted in the renewable energy sector (a statistically significant effect appears from years seven to ten for the latter, but it is positive) (**Table 2-5** and **2-6**). Loss of income during recessions may lead to shifts to cheaper sources of energy such as coal or wood. We do not find any statistically significant increase of the share of coal in the energy mix after a recession, other than a decrease in years t+5 and t+9 (significant at the 0.05 and 0.1 level respectively) (**Table 2-7**). For biomass we do find an increase in consumption one year after the recession, significant at the 0.05 level (**Table 2-8**).

How is this explainable given that recessions are likely to lead to a decline in public and private investment for clean energies, a relaxation of environmental standards or a reduced willingness by the public to pay for environmental improvements or taxes, and use of cheaper and 'dirtier' energy sources (Bowen & Stern 2010)? A plausible hypothesis is that policymakers, investors and the public know that recessions are short-lived (69% of all recessions in our dataset last one year and only 5% four years or more) and weather out their effects rather than proceed to investment, legislative or behavioral changes. An alternative hypothesis is that positive effects, such as a green stimulus, a general reduction of energy consumption or a cancellation of energy-intensive projects, outweigh negative effects. This merits further research but the key finding here is that there is no evidence of rebounding of carbon emissions in the long-term.

The remaining carbon budget to ensure a 66% chance of staying within 2^{o} C is not more than 1000 $GtCO_2$ from 2011 to 2100 (IPCC 2014), leaving some 800 Gt CO_2 for emissions from cement and energy production, until they are zeroed (Anderson 2015). Assuming a similar economic climate to that of 1960-2015, recessions could reduce cumulative emissions up to 3.38%, i.e. saving some 30 GtCO2. This gives one to two years more time for zeroing carbon emissions and one third of the seven or more necessary 'stabilization wedges', i.e. packages of policies/changes that can reduce total emissions by 90 GtCO2 each (Pacala 2004). In the enormous task of fully decarbonizing energy supply, recessions will not make a difference. Given the negative social effects of an unplanned and involuntary economic downturn, there is little to commend about recessions in the fight against climate change (Bowen & Stern 2010).

This is not to dismiss the importance of the scale of economic activity. Growth is the factor most strongly and consistently associated with increasing carbon emissions. Assuming historically observed values of carbon intensity, if global growth were 1% higher each year since 1961, 442.85 $GtCO_2$ more would have been emitted by now; if it was 1% less, 305 $GtCO_2$ less (these values would be different if faster/slower growth and rise of emissions had accelerated/decelerated renewable energy development and policy action). Unlike recessions, these are important sums. In the future, the lower (higher) economic growth is, the slower (faster) carbon intensity has to decline. Global mitigation rates have to ratchet up to around 10% per year by 2025, continuing at such a rate towards 2050 (Anderson 2015). Carbon intensity in energy and cement production declined 36.51% from 1961 to 2014, with 5.03% reduction in 1981 being the highest on record. The future needs not be like the past, but in general science takes the past as a good basis for establishing relations about what the future might look like. Decarbonizing is easier with low or negative growth, than with 2-3% or higher growth. Assuming a 10% rate of decarbonization, then in the short-run the rate of reduction in carbon intensity is equal to 10 + growth rate. A permanently slower economy, rather than a growing economy with occasional recessions, might save vital time for an energy transition within a limited carbon budget. The slowing down can be selective, starting from carbon-intensive, low-wellbeing sectors first. The question is whether and how, unlike involuntary and unforeseen recessions, a planned slowing down can be organized to be prosperous (Jackson 2009;, Victor 2012).

Table 2-4 Effects of recession on carbon emissions and its following ten years.

Variables	***Dependent Variable: ΔLn Carbon Emissions***												
	t-2	***t-1***	***t***	***(t+1)***	***(t+2)***	***(t+3)***	***(t+4)***	***(t+5)***	***(t+6)***	***(t+7)***	***(t+8)***	***(t+9)***	***(t+10)***
Recession$_{i,t}$	-0.0082 (0.004)	-0.0216* (0.004)	-0.0454*** (0.004)	-0.0150*** (0.004)	-0.0095** (0.004)	-0.0092** (0.004)	-0.0031 (0.004)	0.0045 (0.004)	-0.0019 (0.004)	-0.0003 (0.004)	-0.0006 (0.004)	0.0053 (0.004)	-0.0002 (0.004)
Constants	0.2135* (0.035)	0.2340* (0.035)	0.2063*** (0.034)	0.2334*** (0.036)	0.2702*** (0.037)	0.2784*** (0.039)	0.2567*** (0.042)	0.2270*** (0.045)	0.2353*** (0.045)	0.2120*** (0.048)	0.1725*** (0.054)	0.1093* (0.061)	0.0666 (0.074)
Country and year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R^2 (within)	0.0436	0.0486	0.0653	0.0480	0.0488	0.0467	0.0435	0.0429	0.0427	0.0429	0.0375	0.0372	0.0309
Obs	6369	6470	6567	6443	6313	6179	6047	5910	5773	5636	5498	5360	5222

Table 2-5 Effects of recession on renewable capacity and its following ten years.

Variables	***Dependent Variable: ΔLn Renewable Capacity***										
	t	***(t+1)***	***(t+2)***	***(t+3)***	***(t+4)***	***(t+5)***	***(t+6)***	***(t+7)***	***(t+8)***	***(t+9)***	***(t+10)***
Recession$_{i,t}$	-0.0295 (0.097)	0.0547 (0.097)	0.1744* (0.096)	-0.0487 (0.096)	-0.1264 (0.099)	0.1124 (0.099)	0.0656 (0.098)	-0.0814 (0.097)	0.1132 (0.097)	-0.0879 (0.096)	-0.0770 (0.095)
Constants	0.3513 (0.655)	0.2090 (0.689)	0.3154 (0.730)	0.3287 (0.779)	0.3511 (0.838)	0.3783 (0.916)	1.4453 (1.017)	0.6514 (1.172)	0.7884 (1.429)	1.9809 (2.014)	0.0576 (0.533)
Country and year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R^2 (within)	0.0129	0.0133	0.0147	0.0138	0.0141	0.0143	0.0142	0.0135	0.0133	0.0131	0.0128
Obs	3587	3572	3552	3531	3509	3485	3457	3428	3398	3367	3336

Table 2-6 Effects of recession on renewable innovation and its following ten years by using fixed effect negative binomial regression.

	Dependent Variable: Renewable Innovation										
	t	***(t+1)***	***(t+2)***	***(t+3)***	***(t+4)***	***(t+5)***	***(t+6)***	***(t+7)***	***(t+8)***	***(t+9)***	***(t+10)***
Recession$_{i,t}$	0.0926 (0.073)	-0.0652 (0.071)	-0.0135 (0.069)	-0.0094 (0.068)	-0.0385 (0.089)	0.1015 (0.073)	0.1100 (0.078)	0.2466*** (0.069)	0.1770*** (0.064)	0.3019*** (0.062)	0.2769*** (0.064)
Constants	3.9860*** (0.406)	3.8620*** (0.401)	0.4567 (0.501)	0.4065 (0.431)	0.6461 (0.420)	0.9741 (0.155)	1.1621 (0.188)	1.3390*** (0.187)	1.3866*** (0.188)	1.5900*** (0.189)	1.6483*** (0.192)
Country and year	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

fixed effect											
Log-Likelihood	-1766.66	-1767.03	-1767.15	-1767.45	-1722.19	-1590.17	-1586.18	-1513.38	-1444.99	-1352.29	-1277.91
Obs	1016	1016	1016	1016	962	915	854	800	746	692	638

Note: Dependent variables are renewable patent counts, we choose fixed effect negative binomial regression after the Hausman test. Considering data availability we collect data from 34 OECD countries and 20 developing countries include Argentina, Brazil, China, Egypt, Hong Kong, India, Lithuania, Malaysia, Morocco, Philippines, Romania, Russian Federation, Saudi Arabia, Singapore, South Africa, Chinese Taipei, Thailand, Tunisia, Ukraine and United Arab Emirates.

Table 2-7 Effects of recession on percentage of the national fossil fuel use covered by coal and its following ten years.

	ΔLn Coal.%Fossil										
	t	***(t+1)***	***(t+2)***	***(t+3)***	***(t+4)***	***(t+5)***	***(t+6)***	***(t+7)***	***(t+8)***	***(t+9)***	***(t+10)***
Recession$_{i,t}$	0.0101 (0.035)	0.0211 (0.034)	0.0140 (0.035)	-0.0186 (0.034)	-0.0406 (0.033)	-0.0688** (0.034)	0.0133 (0.034)	0.0028 (0.033)	-0.0021 (0.033)	-0.0593* (0.033)	-0.0107 (0.033)
Constants	0.2384 (0.179)	0.2124 (0.186)	0.1852 (0.192)	0.1906 (0.197)	0.2069 (0.205)	0.1488 (0.217)	0.1357 (0.233)	0.1180 (0.254)	0.1001 (0.292)	0.1327 (0.356)	0.1326 (0.501)
Country and year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R^2 (within)	0.0315	0.0331	0.0290	0.0267	0.0281	0.0250	0.0194	0.0167	0.0169	0.0188	0.0172
Obs	2174	2153	2132	2111	2089	2067	2045	2023	2001	1979	1956

Table 2-8 Effects of recession on biomass consumption and its following ten years.

	ΔLn Biomass										
	t	***(t+1)***	***(t+2)***	***(t+3)***	***(t+4)***	***(t+5)***	***(t+6)***	***(t+7)***	***(t+8)***	***(t+9)***	***(t+10)***
Recession$_{i,t}$	-0.0149 (0.015)	0.0302** (0.015)	0.0164 (0.015)	-0.0025 (0.015)	-0.0161 (0.013)	0.0002 (0.011)	0.0049 (0.011)	-0.0011 (0.009)	0.0039 (0.009)	0.0277*** (0.009)	-0.0134 (0.009)
ΔLnAgriculture GDP	-0.0769* (0.040)	-0.0629 (0.040)	0.1351*** (0.041)	0.0374 (0.041)	0.0479 (0.035)	-0.0161 (0.031)	-0.0047 (0.032)	0.0350 (0.026)	-0.0131 (0.027)	0.0261 (0.025)	-0.0065 (0.026)
Constants	0.0399 (0.114)	0.0474 (0.123)	0.0656 (0.133)	0.0474 (0.140)	0.0801 (0.132)	0.0765 (0.132)	0.1087 (0.164)	0.0016 (0.183)	0.0573 (0.056)	0.0553 (0.053)	0.0303 (0.054)
Country and year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R^2 (within)	0.0383	0.0406	0.0447	0.0383	0.0327	0.0215	0.0219	0.0255	0.0254	0.0302	0.0284
Obs	4050	3978	3901	3821	3739	3657	3557	3455	3352	3250	3119

3. Recession and material consumption: A dynamic panel data analysis.

3.1 Introduction: Economic development and material flows

Global material use has increased from approximately 7 billion tons (Gigatons Gt) in the year 1900 (Krausmann et al. 2009) to approximately 70 Gt in 2010 (Schaffartzik, Eisenmenger, et al. 2014). The extraction and use of these large and growing quantities of resources are related to a broad range of sustainability problems and a decoupling of material use and economic development is considered imperative for sustainable development (UNEP 2011a). It has been shown that, however, significant improvements in material efficiency in the past have not lead to an overall reduction of material use (Akenji et al. 2016). Different pieces of evidence point towards economic recession as an important factor in absolute, but ultimately short-term, reductions of material use (e.g., Steinberger et al., 2013). Recession is neither a socially nor an economically sustainable strategy in curbing human societies' impact on the environment but insights on the possibilities of material use reduction might be gained by studying periods characterized by negative economic growth. We have applied a dynamic panel data approach to 150 economies between 1970 and 2010 in order to generate systematic results on the relationship between economic recession and development of material use.

Recession may be defined by decline in economic output per capita (Barro & Ursúa 2008; Kehoe & Prescott 2002), by a combination of declining per capita output and negative economic growth (Breuer & McDermott 2013), or by decline in economic output over a set period of time (Claessens et al. 2009). For the purposes of our study, which relies on annual material flow data, we identified as recession years those years in which economic output declined (Reddy & Minoiu 2009; Burke et al., 2015). Most of the research on recession, by any definition, has, to date, focused on linkages among economic variables and on very severe recessions, i.e., depressions. Claessens et al. (2009) studied linkages between key macro-economic and financial variables, such as inflation, debt, and unemployment in 21 member countries of the Organization for Economic Co-operation and Development (OECD). Breuer & McDermott (2013) comprehensively and globally analyzed economic depression in the world, across long periods of time and for countries and regions of differing development levels, and were able to identify economic, financial, political, and cultural aspects typically associated with depression and also found that domestic and international shocks played an important role in determining the onset or the end of a period of depression. Fisher & Hornstein (2002) focused on Germany during the Great Depression of 1928-37 and found that real wages were countercyclical, i.e., they were not correlated with the changes in economic output, while productivity and fiscal policy were procyclical. Other country-level case studies on economic depression have included Argentina (Kydland & Zarazaga 2002), Chile and Mexico (Bergoeing et al. 2002), and Japan (Hayashi & Prescott 2002). The latter study concluded that the underlying reasons for recession during Japan's "Lost Decade" may have been rooted in the low growth of productivity rather than in the development of the financial system and the capital markets. For the 20-year depression in the United Kingdom between the two world wars, Cole & Ohanian (2002) identified high unemployment benefits and negative sectoral shocks as leading explanatory variables.

With regard to the linkages between economic development and the environment which a recession may bring to light, the relationship with material use has not yet been systematically analyzed. Bringezu et al. (2004) noted that individual countries' direct material input (DMI = domestic extraction plus imports) did change during periods of economic recession, but the specific relation could not be generalized across countries. For Finland, the authors noted that very high levels of material flows had preceded the economic recession. At the aggregate global level, Krausmann et al. (2009) demonstrated that periods of economic recession (during and after the two World Wars and during the world economic crisis 1930-32) coincided with periods of declining domestic material consumption (DMC = domestic extraction plus imports minus exports). The years following the oil price peaks (1973, 1979 and 1988) with their reduced levels of GDP growth were periods of stagnation in global material use. In the development of mineral and fossil fuel use during years of recession, Steinberger et al. (2013) found evidence for short-term coupling between material resource flows and economic development. While many authors mention evidence for a link between economic recession and material use patterns in passing (Behrens et al., 2007; Rogich 1996; Russi et al., 2008; Vehmas et al., 2007), a systematic analysis of this link is not yet available. The aim of this study is to fill this gap by providing a quantitative analysis of material use patterns in periods of economic recession at the national level. We use a dynamic panel data model covering 150 economies to detect whether recession or low economic growth are determining factors for material flows, among other potential impact factors. We consider total material flows as well as material flows by material type (biomass, fossil fuels, construction and industrial minerals, and metals) in order to reflect potential differences in the links of material types to economic development. Such analysis contributes to a systematic understanding of the close interrelations between economic growth and material use at the national level, and subsequently provides a backdrop for in-depth case studies on wider consequences of economic recession on societal resource use. Our findings are also directly policy-relevant: It is becoming increasingly clear that in order to curb the environmental impact of socio-economic activity, resource use levels must be reduced in absolute terms (Akenji et al. 2016). If, however, economic recession has previously constituted a prerequisite to reductions in material use (which we investigate in this article), then the challenge of finding viable and effective ways to deal with the environmental crisis is much greater than previously anticipated.

3.2 Method and data

In assessing the role which economic recession plays for material use levels, we require an analytic approach which allows us to study the relationship between these two (and other background) variables. We must assume that the material use levels are prone to feedback over time. This requires a dynamic model that can capture time lags in the material variable, such as, allowing past material use levels to influence current material use levels. “Static” panel techniques, as regularly used for empirical analysis, do not incorporate any temporal dependency (lags) of the dependent variable, neglecting the fact that environmental indicators (such as CO_2 emission, energy use, or ecological footprint) are likely to correlate strongly over time. Thus, in order to control for the dynamics of the process and test whether significant correlations still explicitly exist under this new framework, we employed a dynamic panel technique that contains lagged dependent variable among the regressors. In this line, we construct a dynamic panel data model of the form below:

$$DMC_{i,t} = aDMC_{i,t-1} + bRecession_{i,t} + cLowGrowth_{i,t} + dX_{i,t} + \mu_i + \varepsilon_{i,t} \qquad (1)$$

The dependent variable $DMC_{i,t}$ denotes the domestic material consumption in country i and year t. Our data cover 41 years (1970-2010), so that t = 1, 2,…,41, and 150 economies, so that i= 1, 2,…, 150. The number of countries for which data are available (N=150) is large compared to the time periods for which data are available (T=41), so that our dataset has the particular structure "large N and small T". We elaborate the model for total DMC here and have also analyzed DMC by material types (biomass, fossil fuels, industrial and construction minerals, metal ores; also see **Table 3-1**). The independent variable $DMC_{i,t-1}$ is the time-lagged dependent variable, i.e., the material consumption in country i in the year preceding t. We have chosen a first order of time lag. $Recession_{i,t}$ denotes whether the country i was in recession (i.e., experienced negative GDP growth) in year t (and then takes on the value 1) or not (in which case this variable has the value 0). We thereby reduce economic growth to a binary variable which allows us to generate an unambiguous answer to the question of whether or not dematerialization only occurs during periods of recession. The precise elasticities of GDP with regard to material use, which cannot be captured using this approach, did not differ strongly within ranges of GDP growth below 3% allowing us to make use of this reduction of complexity without sacrificing information necessary for our analysis. In order to capture quantitative differences in economic growth, we introduced a variable which allows us to capture different levels of growth: takes on the value 1 if country experiences low growth (we distinguish three low growth levels between 0% and 3% GDP growth per year, see **Table 3-1**) in year and takes on the value 0 if this is not the case. A country can thereby either be in recession or low growth or neither in year t. $X_{i,t}$ is a vector of possible socio-economic drivers of material use: GDP per capita, population, the urban population share, the share of value added in the services sectors in GDP, the ratio of monetary exports and imports to GDP, respectively, a time-lagged technology indicator, and a dummy variable of signature of the Kyoto Protocol which takes on the value of 1 from 1998 onwards (see **section 2.2**). The variables contained in $X_{i,t}$ vary over time (differ according to t) and across countries (differ according to i). All indicators except for the dummy variables (i.e., recession, the three low-growth variables, and the signature of the Kyoto Protocol) are logarithmized rendering a log-log regression model. The elasticity between the dependent and the explanatory variables therefore corresponds to the regression coefficient. That is to say that one unit increase in the independent variable causes a change in the dependent variable corresponding to the value of the coefficient, hold other variables unchanged. μ_i represents the unobserved effects which are specific to country i but are time-invariant. Because these effects are stochastic ($\mu_i \sim i.i.d(0, \sigma_{\mu_i})$), they are necessarily correlated with the time-lagged dependent variable. $\varepsilon_{i,t}$ is a stochastic disturbance term ($\varepsilon_{i,t} \sim i.i.d(0, \sigma_\varepsilon)$).The expected value (or weighted average) $E(\mu_i, \varepsilon_{i,t}) = 0$.

Since the time-lagged explanatory variable is positively correlated with the error term ($\mu_i + \varepsilon_{i,t}$), we cannot use ordinary least squares to estimate the regression coefficient of the time-lagged variable. Instead, we employ the Arellano–Bond (AB) generalized method of moments (GMM) estimator (Arellano & Bond 1991; Roodman 2010). This estimator was developed and extended to the system GMM context (Blundell & Bond 1998) for dynamic models of panel data characterized by "large N and small T", explanatory variables that are not strictly exogenous, and heteroscedasticity within the errors (by but not across countries, in our case) as is the case in our dataset and dynamic model. The system GMM estimators afford the advantage of relying on instruments available within the panel. In a system of two simultaneous equations, the first-differenced equation (with lagged levels of explanatory variables as instruments) is combined with the levels equation (with lagged first differences of the explanatory variables as instruments) (Nguyen et al. 2014).

Three criteria are employed in our analysis to test the results. First, we test for autocorrelation in the errors by using the Arellano–Bond AR(1) and AR(2). Specifically, AR(1) tests for first order serial correlated residues and AR(2) tests for serial uncorrelated residues of second order. We reject the result if for AR(1) $P < 0.05$ but accept the result if for AR(2) $P > 0.05$. In addition, the Sargan test was used to check instrument validity which was considered reasonable if the Sargan P-values did not reject the null hypothesis (H0: over-identifying restrictions are valid). A rule-of-thumb is that the number of instruments should be less than the number of counties (Schumacher 2014).

3.2.1 Dependent variables: material flow data

The dependent material consumption variables in our dynamic model were derived from material flow data. This data is obtained by material flow accounting (MFA) which is one of the key methods in environmental accounting (Fischer-Kowalski et al. 2011). The annual material flow data for a global country sample used in our analysis was obtained from the United Nations Environment Programme (UNEP) material flow dataset (2016). This database contains material flow data at the national level in kilotons per year (kt/a), covering the period 1970 to 2010. On the basis of this data, we calculated domestic material consumption (DMC = domestic extraction plus imports minus exports) by main material group (biomass, fossil fuels, non-metallic minerals, and metal ores) and in total. Biomass comprises products from agriculture, forestry, fishing, and hunting. Fossil fuels encompass coal and peat, oil, and natural gas as well as any derived products. Non-metallic minerals comprise all minerals for industrial use and construction. Metal ores include all metallic ores, metals and derived products. The DMC indicator does not include unused or upstream flows related to imports or exports (Fischer-Kowalski et al. 2011).

The period between 1970 and 2010 comprises the dissolution of the USSR, Czechoslovakia, and Yugoslavia. We included these economies in our data panel until the year of their dissolution and then accounted for the independent countries that emerged from them. The numbers of economies for which data are available differ from one year to the next (also see **Table 3-1**).

3.2.2 Independent variables: socio-economic data

The primary source of data for the independent or explanatory variables was the World Development Indicators Database (World Bank 2016). While some of these variables are commonly used in studies relating socio-economic development to environmental factors, others (such as the recession variable and the technology variable) constitute aspects which have not been taken into account by previous studies.

We seek to understand the relationship between material use and economic recession. The Recession indicator is therefore central to our analysis. This variable is based on GDP growth in annual % as reported by the World Bank (2016) in its World Development Indicators, i.e., based on annual average in constant prices. The Recession indicator takes the value of 1 if GDP decreases (i.e., during years with negative economic growth) and of 0 in all other years, following the definition of recession used by Reddy & Minoiu (2009) and Burke et al. (2015). The LowGrowth indicator can take on one of three levels: 1) GDP growth rates ranged between 0-1%, 2) GDP growth between 1-2%, and 3) GDP growth between 2-3%. For each of these levels, this indicator takes on the value of 1 if the low growth criterion is met and of 0 if this is not the case.

Our aim is to design a dynamic model which allows us to investigate the effect of socio-economic variables on material use across countries and over time. We therefore added several potentially important socio-economic control variables to the model:

1) Real GDP per capita (GDP p.c) in US$ in constant 2005 prices in order to allow for an impact of income on material use,

2) Total population (Population), which is essential to account for size differences across countries,

3) Urban population ratio (Urban % P) as a proxy for the population living under the industrial socio-metabolic mode, i.e., depending on a fossil fuel based energy system (Fischer-Kowalski & Schaffartzik 2015),

4) Value added by the services sector as percentage of GDP (Service % GDP) as a proxy for economic structure,

5) Exports and imports of goods and services in percentage of GDP (Export % GDP and Import % GDP) to capture the role of trade for the country,

6) Number of patents filed under the Patent Cooperation Treaty (Technology (t-1)) as an indicator for technology. This variable is lagged by one year (t-1) to account for the time lag in patent diffusion (Cheon & Urpelainen 2012; Bayer et al., 2013). Data were sourced from the OECD Patent Statistics Portal (Version 2011), and

7) Signature of the Kyoto Protocol (KP) as a dummy variable which takes on the value 1 after the signing of the Kyoto Protocol in 1998 and of 0 before that. We chose this variable in order to

test the results of previous studies which showed an effect of the Kyoto Protocol on CO_2 emissions (Aichele & Felbermayr 2014).

All the selected variables and their summary statistics are provided in **Table 3-1**, which contains the definition, numbers of observations, descriptive statistics and sources. It shows that for both the dependent and independent variables, there is considerable variation across observations

Table 3-1. Summary Statistics

Variables	Definition and units	Observations	Descriptive Statistics				Source
			Mean	**Std. Dev**	**Min**	**Max**	
Material variables							
DMC	Domestic material consumption, kilotons [kt]	6150	253,004.3	946,360.3	0	2.36e+07	UNEP (2015)
DMC-Biomass	Biomass [kt]	6150	81,491.35	240,195	0	3,250,108	
DMC-Fossil Fuels	Fossil fuels [kt]	6150	53,052.01	220,949.3	0	3,724,362	
DMC-Minerals	Industrial and construction minerals [kt]	6150	92,565.34	471,696.6	0	1.46e+07	
DMC-Ores	Metal ores [kt]	6150	25,895.54	94,885.44	0	1,986,819	
Socio-economic variables							
Recession	years of GDP decline (value 1 or 0)	5358	0.1698	0.3755	0	1	Based on GDP growth (World Bank 2016)
Low-Growth (0-1%)	years of growth rate between 0-1% (1 or 0)	5358	0.0575	0.2328	0	1	
Low-Growth (1-2%)	years of growth rate between 1-2% (1 or 0)	5358	0.0752	0.2638	0	1	
Low-Growth (2-3%)	years of growth rate between 2-3% (1 or 0)	5358	0.0944	0.2925	0	1	
GDP p.c.	GDP per capita, constant 2005 US$/cap	5283	8,703.99	13,009.14	111.79	87,716.73	World Bank (2016)
Population	Total population (cap)	6147	3.42e+07	1.20e+08	84,370	1.34e+09	
Urban % P	Urban population ratio, % of population	6150	51.14	24.59	2.85	100	
Service % GDP	Services, etc., value added , % of GDP	4845	50.65	13.53	2.96	92.84	
Export % GDP	Exports of goods and services, ratio to GDP	5253	35.90	27.66	0.18	523.46	
Import % GDP	Imports of goods and services, ratio to GDP	5261	39.27	24.75	0.12	213.48	
Technology (t-1)	Filed patent counts (one-year lagged)	1986	701.24	3632.80	0	52,068.32	OECD.Stat
KP	Kyoto Protocol (1 or 0)	6150	0.32	0.47	0	1	-

3.3 Results and discussion

Between 1970 and 2010, global material use[1], measured here as DMC, increased by a factor of 2.9, from 23.2 Gigatons (Gt) in 1970 to 68.1 Gt in 2010. The strongest growth during this period occurred in the use of non-metallic minerals for construction and industrial use (factor 4.7). Consumption of metals grew by factor 3.1 and fossil fuels and biomass each grew by factor 2.2. Until 1990, when it was overtaken by construction and industrial minerals, biomass use was the largest of the four material types. The global gross domestic product (GDP) increased by a factor of 3.8 from 14.32 trillion US$ (2005 constant) in 1970 to 54.47 trillion US$ in 2010. While these figures suggest similar material and economic growth across the whole time period, a closer look at the development of GDP and DMC from one year to the next allows for the identification of different phases of growth in both macro-indicators.

Between 1970 and 2010, the only phase of global dematerialization (decreasing material consumption) occurred between 1990 and 1992 when DMC decreased from 39.59 to 38.90 Gt/a coinciding with a noticeable change in global GDP growth (see **Fig.3-1**). This observation corresponds to the findings of Krausmann et al. (2009). During this time, the Gulf War broke out and was followed by the third oil price crisis. The global economic crisis which began in 2007/2008 and resulted in a decline in global GDP between 2008 and 2009, coincided with lower growth of material use compared to the years preceding the crisis. Absolute global material use, however, increased compared to the pre-crisis level (**Fig. 3-1**).

[1] Here, and throughout the article, we rely on a sample of 150 economies (a list can be found in the **Appendix 2**) to represent global material use. In 2010, these 150 economies accounted for 97.41% of total global material use as estimated by Krausmann et al. (2009).

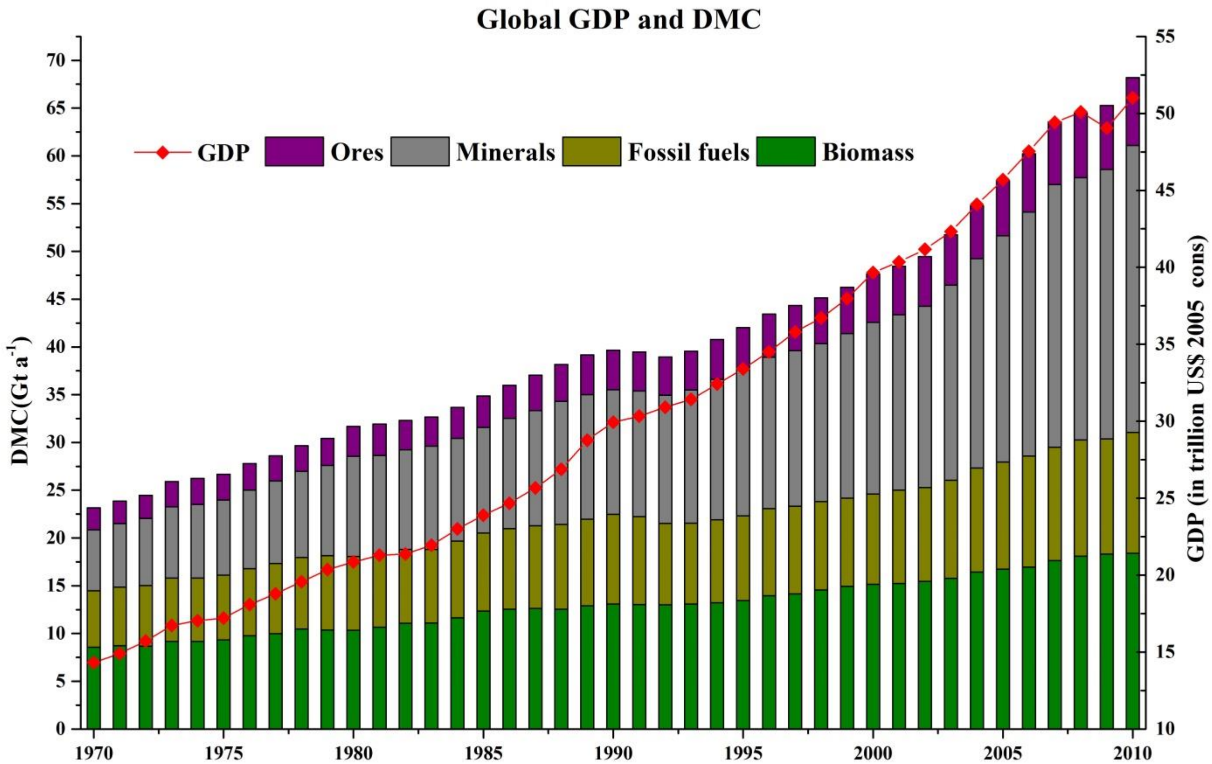


Fig.3-1. DMC by material types in Gigatonnes per year (Gt a^{-1}, primary y-axis) and total GDP (in trillion constant 2005 US$; secondary y-axis) for 150 economies. Data sources: UNEP (2015), World Bank (2016).

3.3.1 Occurrence of recession across countries and over time

To empirically examine the relationship between material usage and economic development, we define the years as 'recession' in which negative GDP growth occurs. This definition allows for a binary distinction between years in which recession did or did not occur in any given country. An overview of the frequency of the recession country-years and countries in recession per decade (with the first decade, from 1970 to 1980, spanning 11 years and all other decades spanning ten years) is presented in Table 2. From the first to the second decade, the share of recession country-years (i.e., of the number of countries multiplied by the number of recession years) in total country years (total number of countries multiplied by years in the decade) increased from approximately 15% to approximately 24% and dropped thereafter to 19% and 12% in the decade from 2001-2010. Another way to consider the data is by the number of countries that spent at least one year in recession during a decade (countries in recession in **Table 2**): The Democratic Republic of Congo, for example, experienced declining GDP from 1989 to 2001 and is counted as a recession country in the three decades from 1981-1990, from 1991-2000, and from 2001-2010. The share of recession countries in total countries varied from 61% in the last decade to 77% in the second decade (1981-1990).

By both measures, the 1980s and, to a lesser degree, the 1990s, stand out. During the 1980s, known for the debt crisis in Latin America and the world wide credit crunch, among others, 77% of the countries experienced at least one year of recession and 24% of the country-years were spent in recession. There was improvement in the 1990s although recession was not uncommon (71% of countries experienced at least one year of recession). This decade encompasses the Gulf War and following oil crisis and the Japanese and Asian financial crisis of 1997/1998. In Thailand, for example, GDP growth dropped to -10.5% in 1998 and in Indonesia, the largest economy in Southeast Asia, GDP growth decreased to -13.1% in that same year. After 2000, the incidence of recession falls considerably and out of the 180 recession country-years in the last decade, more than half occurred during the last three years from 2008-2010.

Table 2. Overview of recession country-years and recession countries by decade between 1970 and 2010. Source of data: World Bank (2016).

	1970-1980	1981-1990	1991-2000	2001-2010	Trend
Recession country-years	170	302	276	180	
Total country-years	1163	1276	1450	1466	
Share of recession country-years (%)	14.62	23.67	19.03	12.28	
Countries in recession	75	107	105	91	
Total countries	110	138	146	149	
Share of countries in recession (%)	68.18	76.98	71.43	61.07	

3.3.2 Material use under recession in the USA, Germany, Japan, and Brazil

The country-level recession data presented in **Table 2** shows that negative economic growth occurs more frequently throughout the observed time period than the global totals (**Fig.3-1**) may have led us to expect. In order to discuss the development of economic growth and material use in conjunction with one another before we turn to the results of our dynamic panel data analysis, we here present growth rates in the underlying indicators for a selection of four countries: the United States of America (U.S.), Germany, Japan, and Brazil. During the time period covered, the U.S. was the largest economy. Germany was the largest economy in Europe and implemented a number of energy- and resource-efficiency policies, the effect of which we are interested to observe. Japan represents the Asian continent and experienced well-known periods of recession, especially during the late 1990s. Brazil, as an emerging economy in Latin America, experienced different development trajectories during this time period, and we are interested to see how it compares to the other three economies which experienced their industrial take-off phases earlier. Because of their size, China and India are often singled out as case study countries. However, neither of these countries experienced GDP downscaling over the past four decades so that we will not individually discuss them here.

The U.S. experienced periods of negative GDP growth from 1973-74, 1981-82, 1990-91, and 2007-09 (**Fig.3-2a**). Each of these periods is also marked by decreasing DMC, i.e., by dematerialization during periods of recession. DMC also decreased from 1994-95 and 2001-02, when GDP growth rates were 2.72% (within our third LowGrow definition) and 0.95% (within our first LowGrow definition) respectively.

Stagnation in DMC growth or dematerialization in Germany (**Fig.3-2b**) mostly coincided with GDP growth, although recessions (with dematerialization) did occur 1974-75, 1981-82, 1992-93, 2002-03 and 2008-09. Out of the 41-year period, 21 years fell into one of our LowGrow definitions with GDP growth between 0 and 3%. DMC declined from 1994 to 1998 with an average annual GDP growth rate of 1.71%, providing an example of dematerialization under low growth conditions.

Japan experienced negative GDP growth from 1973-74, 1997-99 and 2007-09. During all these periods, DMC also declined (**Fig.3-2c**). Dematerialization under low growth rates as it occurred in Germany in the 1990s, occurred in Japan in the first years of the 21st century. From 2000-05, DMC decreased by 9.7% while GDP grew at an average of 1.38% per year. During these phases, Japan and Germany achieved what is referred to as absolute decoupling of material use and economic growth (UNEP 2011b).

Compared to the other three countries, Brazil was on a DMC growth trajectory during the 41-year period studied here (**Fig.3-2d**). This is a trait it shares with other large, emerging economies such as India and China. Nonetheless, (short) phases of low DMC growth or even dematerialization did occur: For example, from 1980-81, both DMC and GDP declined. However, in Brazil, low growth of GDP also coincided with rising material consumption. Between 1997 and 1998, for example, GDP growth (at 0.04%) fell into our first LowGrow definition while DMC increased by 2.48%.

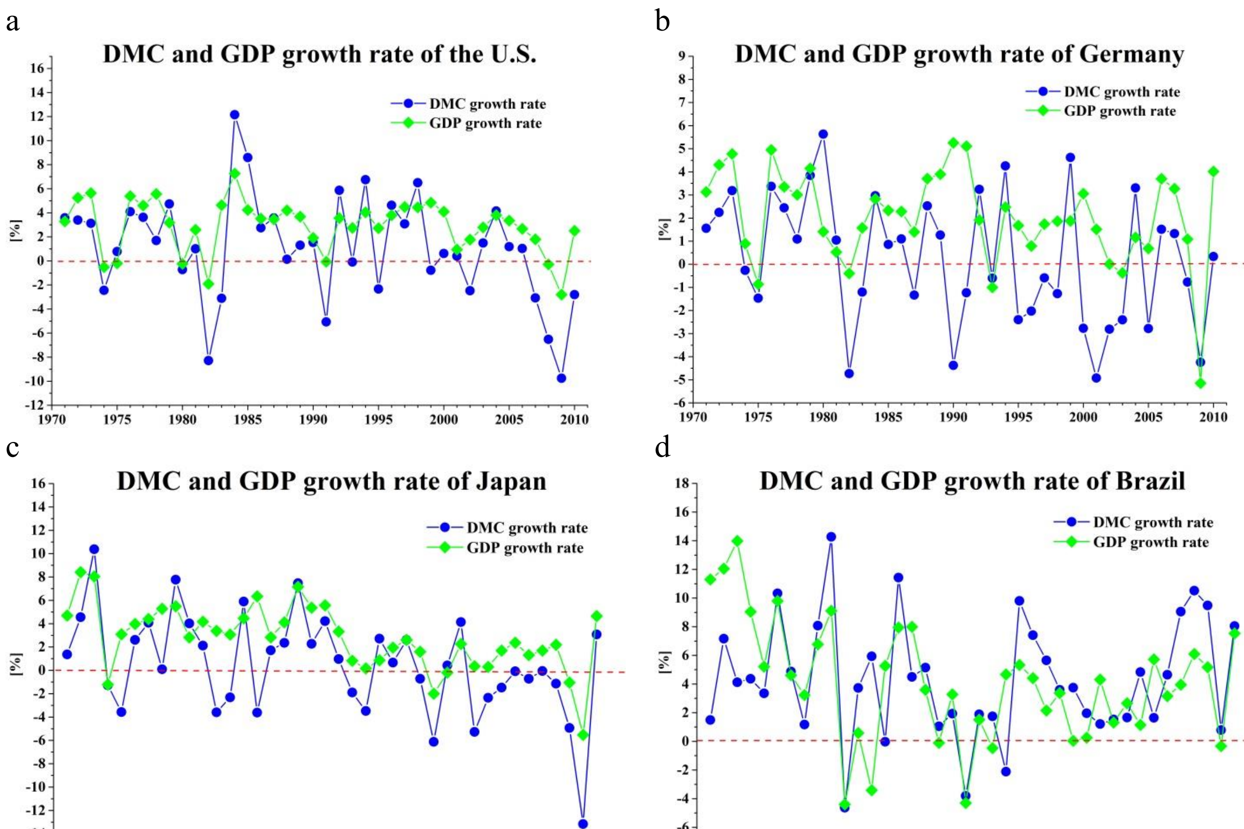


Fig.3-2. Gross domestic product (GDP) and domestic material consumption (DMC = domestic extraction plus imports minus exports) growth rates in the United States of America (U.S.), Germany, Japan, and Brazil during 1970-2010. Please note the differences in scaling of the y-axis. Data sources: Anon (2016), World Bank (2016).

3.3.3 Impacts of recession and low GDP growth on material use.

We first tested for stationarity of the panel data by applying the panel unit root test before regression. **Table 3-3** displays the results of Fisher's test, considering the unbalanced nature of our panels. The null hypothesis is that all panels have non-stationary time series. Therefore, if the null is rejected in levels, the series is assumed to be I (0); if the null fails to reject when in levels, but is rejected when in first differences, the series is assumed to be I (1). Results suggest that variables, except for *Oil Price* and *Kyoto Protocol*, are I (0).

Table 3-3. Results for panel unit root test.

	Variables in levels		***Variables in first differences***	
	Statistic	*Prob*	*Statistic*	*Prob*
DMC	505.6956	0.0000***	2390.2648	0.0000***
Recession	1475.0729	0.0000***	4924.6855	0.0000***
GDP p.c.	344.8513	0.0220**	1536.7189	0.0000***
Population	722.8675	0.0000***	1911.4442	0.0000***
Urban % P	770.5793	0.0000***	362.9975	0.0074***
Service % GDP	429.4552	0.0000***	2035.1150	0.0000***
Export % GDP	538.8598	0.0000***	2369.1151	0.0000***
Import % GDP	545.4014	0.0000***	2348.4349	0.0000***
Technology (t-1)	319.7890	0.0000***	1305.6822	0.0000***
Oil Price	51.2509	1.0000	1801.6620	0.0000***
KP	146.3669	1.0000	1796.3072	0.0000***

Notes: All variables are logarithmized except for *Recession*; *, **, *** indicate rejection of the null hypothesis at 10%, 5% and 1% significance level.

An overview of the panel regression results we obtained for the effects of recession and low GDP growth on total DMC is presented in **Table 3-4**. We separately studied four models with regard to recession or low GDP growth: In the recession model (results in the first column), the dummy variable in the regression model took on the value 1 if GDP growth was negative. In the first low growth model (results in the second column), the dummy variable took on the value of 1 if GDP growth was between 0 and 1%. For the second low growth model (third column), GDP growth between 1 and 2% was decisive in terms of the dummy variable and for the third low growth model (fourth column), GDP grew between 2 and 3% for the dummy variable to take on the value 1. As expected, AR(1), AR(2) and the Sargan test confirmed the credibility of the results.

We find that the occurrence of recession is significantly and negatively correlated with DMC. Low GDP growth between 0 and 1% is less significantly but also negatively correlated with GDP. For low GDP growth between 1 and 2%, the significance is even lower and for GDP growth between 2 and 3%, we no longer obtain a significant correlation with DMC. Overall, the higher GDP growth was, the less significant we found the correlation with DMC to be. Because we studied a log-log model (see **section 2**), the regression coefficient corresponds to the elasticity: In recession years, DMC decreased by 4.9% on average while during low growth (0-1%) years, it decreased by 3.9% and by 2.9% for growth between 1 and 2%.

Out of the eight socio-economic control variables, only half show significant correlation with DMC. Per capita GDP (*GDP p.c.*) has positive correlations with DMC under all four recession and low growth models at 5% and 10% significance levels. This corroborates the finding of previous studies that income is a driver of DMC growth, regardless of the current phase of economic growth that a country is in (Steinberger et al., 2013; 2010). Population is also positively correlated with DMC under all four models at a 1% significance level: More people use more material, even if the economy is in recession. Urban population which we included as a proxy for the share of the population living under the industrial mode is also positively correlated with DMC at a 5% significance level. This result corresponds to the expectation that the typical industrial metabolic profile is characterized by high and approximately equivalent shares of biomass, fossil fuel, and construction mineral consumption, as compared to a subsistence mode based more strongly on agricultural activity (Fischer-Kowalski & Schaffartzik 2015). The share of the services sector in GDP reflects economic structure with a higher share indicating a dominance of economic activities with less direct material intensity. Studies on the material footprint, i.e., on an indicator of material use which allocates material extraction, no matter where in the world it occurs to country of final demand for goods and services which required this material in their production, have highlighted that even highly industrialized economies with a high share of the tertiary sector in their GDP continue to rely indirectly on material extraction in the primary sectors of other countries (Wiedmann et al. 2015). At a 5% significance level, the share of services in GDP was negatively correlated with DMC. Under economic recession and all three low growth models, countries in which the services sectors played a more important role were more likely to experience dematerialization. Out of the four economies we presented as examples (**Fig.3-2**), Germany and Japan are both characterized by high shares of the tertiary sector in GDP (69% and 72%, respectively, in 2015) (World Bank 2016). This socio-economic variable forms part of the explanation as to why material use in these two countries decreased so strongly during periods of recession. In economies with a high share of the tertiary sector in GDP, recession has a comparatively strong effect on material-intensive activities like construction and primary extraction of building materials (and metals where this activity exists) which are responsible for a large share of DMC. In these economies (which have accumulated a high level of manufactured capital in infrastructures and buildings), vulnerability of the physical economy to economic shocks is high, in spite of the monetary dominance of the less material-intensive tertiary sector. No significant relationships appeared for the share of exports and imports of GDP in this panel. This was to be expected because the material use variable we studied (DMC) includes the balance of trade flows but does not (without further information on trade flows) allow for the distinction between export- or import-dependent countries. With regard to the Kyoto Protocol indicator and in light of previous research which showed its correlation to carbon dioxide emissions, this same effect cannot be replicated for total material use but may be relevant in our results of DMC by material category which we present in the following.

Table. 3-4. Panel regression results under recession and low growth conditions.

Variable		**Model** **DMC under recession**	**DMC under low growth 0-1%**	**DMC under low growth 1-2%**	**DMC under low growth 2-3%**
Time-lagged variable	*DMC (t-1)*	0.9256*** (0.008)	0.9298*** (0.008)	0.9168*** (0.008)	0.9230*** (0.008)
Recession		-0.0487*** (0.014)			
Low growth	*0-1%*		-0.0392** (0.02)		
	1-2%			-0.0291* (0.016)	
	2-3%				-0.0242 (0.015)
Control variables	*GDP p.c.*	0.0180* (0.009)	0.0134** (0.009)	0.0223** (0.009)	0.0203** (0.01)
	Population	0.0698*** (0.009)	0.0651*** (0.009)	0.0788*** (0.009)	0.0732*** (0.009)
	Urban % P	0.0412** (0.018)	0.0381** (0.018)	0.0384** (0.017)	0.0364** (0.018)
	Service % GDP	-0.0816** (0.033)	-0.0676** (0.033)	-0.0755** (0.033)	-0.0746** (0.033)
	Export % GDP	0.0105 (0.023)	0.0115 (0.023)	0.0062 (0.023)	0.0059 (0.023)
	Import % GDP	-0.0087 (0.025)	-0.0088 (0.025)	-0.0046 (0.025)	-0.0029 (0.025)
	Technology (t-1)	0.0001 (0.003)	0.0011 (0.003)	0.0001 (0.003)	-0.0001 (0.004)
	KP	-0.0056 (0.012)	-0.0076 (0.012)	-0.0027 (0.012)	-0.0042 (0.012)
Constant		-0.2328 (0.210)	-0.2183 (0.209)	-0.3335 (0.210)	-0.2959 (0.210)
Observations		1781	1781	1781	1781
AR(1)		0.000	0.000	0.000	0.000
AR(2)		0.912	0.944	0.965	0.994
Sargan P-value		0.844	0.871	0.865	0.849

Note: All variables are logarithmized; standard errors in parentheses; *, ** and *** denote significant p-values at 10%, 5% and 1% levels, respectively.

3.3.4 Impacts of recession and low GDP growth on material use categories

In addition to analyzing the effect of recession and low growth on material use, we split the dependent variable (DMC) into four material categories – biomass, fossil fuels, non-metallic minerals (industrial and construction minerals), and ores – in order to detect whether material use by categories is affected to the same degree by recession or low economic growth as total DMC. Previous research has indicated that determinants of these specific material groups differ, mostly between biomass and the other material categories (Steinberger et al. 2013).

The effects of economic recession or low growth (0-1%) on DMC in the four material categories are shown in **Table 3-5**. Recession is significantly (at the 1% level) and negatively correlated with material use of fossil fuels, of industrial and construction minerals and of metal ores. Biomass is the only material category for which no significant correlation could be detected. This reflects that biomass used for human nutrition and animal feed is highly prioritized across countries, even in times of economic recession as was suggested by Krausmann et al. (2009) in assessing the development of global material use levels. In contrast, the impact of recession appears to be especially strong on non-metallic minerals: During one year of recession, material use in this category decreased by an average of 16%. This change is mainly caused by a decline in use of construction minerals (which are minerals used in bulk for construction purposes such as limestone, sand and gravel), as the use of these materials is closely tied to the economic activity in the material intensive construction sector (Giang & Sui Pheng 2011). Although Keynesian stabilization policy suggests infrastructure investments in times of recession, this may occur with a certain time lag after the initial recession periods and an increase of material use along with infrastructure investments usually emerges in subsequent growth periods (Wigren & Wilhelmsson 2007).

Use of metal ores, in which ferrous ores required for the production of steel play an important role, decreased by an average of 15% during one year of recession. This resembles the pattern found for non-metallic minerals and is related to the high share of steel and other metals used in construction and often in combination with non-metallic minerals (e.g., in reinforced concrete)

(Allwood et al. 2012). The interlinkage of the material-intensive construction sector and economic growth/recession clearly require more attention in the discussion of dematerialization. The impact of recession on fossil fuel use was noticeable but less pronounced than for metallic and non-metallic minerals: During one year of recession, their use decreased by an average of 5%. This suggests that the major share of activity which requires fossil energy input continues even in times of recession. This interpretation is supported by the positive correlation between fossil fuel consumption and per capita income which we detected via the control variables.

In the low GDP growth model (GDP growth rates between 0 and 1%), significant (at the 1% level) negative correlations could only be detected for industrial and construction minerals and for metal ores, illustrating that consumption of these materials could decrease very noticeably, even if low GDP growth occurred. Although at very low levels of GDP growth, this was the most important potential decoupling effect which we observed.

Under recession and low growth, we found significant (1%) positive correlation between population and fossil energy and metal ores consumption. A remarkable effect with regard to population is the significant (5%) positive correlation between the urban share of the population and biomass consumption during recession and low growth years. Under the industrial mode (for which we use the share of urban population as a proxy), an important share of biomass consumption is for human consumption, directly or indirectly (e.g., as animal fodder) which appears not to be negatively impacted by recession or low growth. This potential causal link is not yet well-understood and merits further investigation. The material categories of industrial and construction minerals and metal ores are the only ones for which the trade variables exhibit any significance. Especially noteworthy is the significant (1 and 5%) negative correlation between the ratio of imports to GDP (*Import % GDP*) and consumption of ores under the recession and the low growth model: Comparatively high spending on imports may suggest low levels of domestic production and possibly less resilience in the face of recession or low growth.

Non-metallic minerals and metals used in large quantities in construction (such as steel) and other material-intensive industries appear to be more sensitive to economic fluctuations than the throughput-dominated flows of biomass and fossil fuels. This may relate to the fact that fossil materials (fuel) are essential to the functioning of the modern, industrial society and biomass (food and feed) is irreplaceable in its role of sustaining the human population (with specific dietary patterns) so that the use of these two material categories is less strongly (and/or not immediately) affected by economic recession. In contrast, minerals and metals are used in material-intensive construction and industry sectors which are immediately vulnerable to recession.

Variable		Model							
		DMC-Biomass		DMC-Fossil Fuels		DMC-Minerals		DMC-Ores	
		under recession	under low growth	under recession	under low growth	under recession	under low growth	under recession	under low growth
Time-lagged variable	*DMC-X (t-1)*	0.9344***	0.9341***	0.9467***	0.9527***	0.9692***	0.9670***	0.9376***	0.9285***
		(0.04)	(0.041)	(0.02)	(0.019)	(0.018)	(0.019)	(0.015)	(0.017)
Recession		-0.0056		-0.0526***		-0.1628***		-0.1571***	
		(0.022)		(0.015)		(0.018)		(0.034)	
Low Growth	*0-1%*		-0.0323		0.0163		-0.0657***		-0.1152***
			(0.027)		(0.013)		(0.017)		(0.039)
Control variables	*GDP p.c.*	-0.0205	-0.0223	0.0337**	0.0346**	0.01308	0.0270*	-0.0287**	-0.0212
		(0.013)	(0.014)	(0.014)	(0.014)	(0.015)	(0.016)	(0.015)	(0.017)
	Population	0.0327	0.0319	0.0637***	0.0603***	0.0322	0.0402*	0.0450***	0.0528***
		(0.032)	(0.032)	(0.023)	(0.022)	(0.021)	(0.022)	(0.018)	(0.02)
	Urban % P	0.0602**	0.0614**	0.0167	0.0067	0.0048	-0.0192	0.1000***	0.0927**
		(0.026)	(0.029)	(0.022)	(0.019)	(0.014)	(0.013)	(0.032)	(0.039)
	Service % GDP	-0.2808*	-0.2772*	-0.0194	-0.0097	-0.0095	-0.0068	0.0138	0.0071
		(0.017)	(0.168)	(0.036)	(0.034)	(0.057)	(0.064)	(0.09)	(0.092)
	Export % GDP	-0.0635	-0.0621	0.0158	0.0094	-0.0212	-0.0449*	0.1045**	0.0906*
		(0.053)	(0.05)	(0.021)	(0.02)	(0.021)	(0.024)	(0.049)	(0.056)
	Import % GDP	0.0161	0.0129	0.0122	0.0204	0.0247	0.0550**	-0.1467***	-0.1397**
		(0.036)	(0.035)	(0.024)	(0.023)	(0.024)	(0.026)	(0.053)	(0.061)
	Technology (t-1)	0.0175*	0.0181*	-0.0046*	-0.0062**	-0.0049	-0.0076**	0.0117*	0.0123*
		(0.01)	(0.011)	(0.003)	(0.003)	(0.003)	(0.003)	(0.007)	(0.007)
	KP	-0.0108	-0.0119	-0.0087	-0.0048	0.0087	0.0171	-0.0311	-0.0256
		(0.014)	(0.013)	(0.009)	(0.009)	(0.01)	(0.011)	(0.029)	(0.031)
Constant		1.367	1.3859	-0.8525**	-0.8747***	-0.2466	-0.4273	-0.2249	-0.2771
		(0.967)	(0.993)	(0.344)	(0.335)	(0.388)	(0.446)	(0.532)	(0.59)
Observations		1770	1770	1719	1719	1770	1770	1681	1681
AR(1)		0.017	0.016	0.072	0.074	0.001	0.000	0.000	0.000
AR(2)		0.568	0.584	0.179	0.2	0.604	0.855	0.669	0.677
Sargan P-value		0.998	0.995	0.994	0.991	0.23	0.017	0.984	0.92

Table 3-5. Panel regression results of the effects of recession/low-growth on four material categories of DMC; Note: All variables are logarithmized; standard errors in parentheses; *, ** and *** denote significant at 10%, 5% and 1%, respectively.

3.4 Conclusion

Dematerialization, the reduction of absolute levels of material resource consumption, is a prerequisite to tackling some of the most pressing environmental issues of our time and to achieving a sustainability transformation. Using a dynamic panel data model to analyze the relationships between material flow and socio-economic indicators for 150 economies from 1970 to 2010, we found that globally, dematerialization coincided with periods of economic recession which occurred most frequently and in the largest number of countries during the 1980s and the 1990s. In the early 1990s, the high number of countries in recession can be linked to a decline in global material use. In four important economies (the U.S., Germany, Japan, and Brazil), periods of economic recession were always also periods of dematerialization. In contrast, GDP growth, even at low levels between 2 and 3%, made the occurrence of dematerialization very unlikely. Where dematerialization did occur (during periods of recession or low growth), not all material categories were equally impacted: While the use of industrial and construction minerals and metals was most likely to decrease, fossil fuels and biomass were less likely to react to these economic changes. Dematerialization was not only coupled to the economically undesirable condition of recession or low growth; it also appears to have contributed to curbing anthropogenic greenhouse gas emissions.

At high levels of population, affluence, and urbanization, material use was likely to remain high (and grow) even during times of economic recession or low economic growth. The higher the share of the service sector was in GDP; the more likely dematerialization was to occur.

Our results highlight an urgent need to rethink resource policies internationally, especially with regard to much-needed absolute reductions in resource use. Politically (and also socio-economically) attractive goals in other policy areas (including high and growing levels of wealth and access to modern energy) have yet to be disconnected from growing material resource use. The prevalence of the tertiary over the primary sector, which was found to have a positive effect on dematerialization, can only be implemented internationally if overall material resource use levels are reduced: Even in the highly industrialized economies in which services contribute a large share of GDP, the material footprint (i.e., material use, no matter where in the world it occurs, required for final consumption of goods and services) has continued to grow (Wiedmann et al. 2015). The material use of these countries requires material extraction elsewhere.

Considering the high level of current global material resource use and its continuous growth from 1970 to 2010, it is surprising how many countries intermittently experienced periods of dematerialization. We did not, however, find examples of such dematerialization occurring in a sustainable manner. Instead, evidence for long-term changes in resource use patterns is lacking: Following periods of economic recession and reduction in material use, the material use indicator often quickly returned to previous levels.

Examples for successful environmental policies are few as it is. By studying countries which are able to maintain low levels of material use and resume economic growth, we may gain insights on ingredients of a sustainability transition. We propose to study in greater detail the level of renewed GDP growth at which countries return to their pre-recession patterns of material use, to consider the impacts on material use of policies to counteract recession (e.g. Keynesian investments in infrastructure, austerity measures, etc.), and to consider the country-specific socio-economic factors which further explain the observed relation between material use and economic growth patterns. The pivotal role of accumulated material stock (in buildings, infrastructures, and durable products) in the early industrializers must constitute a particular focus: Our study has shown that construction minerals strongly contribute to dematerialization during recession. Simultaneously, the investment of capital in infrastructure is often promoted to avoid or curb recession. Better understanding the interlinkage of the material-intensive construction sector and recession is imperative to assessing the impact of such policies on resource use.

4. Empirical analysis of the effect of working time on environmental pressure for EU-15, 1970-2010.

4.1 Introduction

The growing amount of attention on working time issues in academic communities and policy arenas is partly owing to their wide associations with income inequality, labor markets (Chang et al., 2011; Blank 2014), and well-beings (Becchetti et al., 2012; Pouwels et al., 2008). Nevertheless, policies to promote environmental pressures reduction through less working hours are becoming an increasingly essential part of the climate change agenda worldwide in the past decades, and there has been considerable interests in understanding the effect of less working hours on environmental degradations in theory and in practice. To be specific, in theory, the group critiquing of growth advocates “a-growth” or protection of the planet`s regenerative capacities through reducing working hours (Pullinger 2014), and supporters of economic de-growth puts forward work time reduction propositions, such as “four-day workweek”, to improve employment condition and abate environmental pressures (Kallis 2013), especially after the 2008 global crisis. In practice, working time reduction policies enacted in Japan, France and Denmark are remarkably different in terms of unique socio-economic contexts, which are also worth deep analysis (Schreiber 2008; Kuroda 2010; Grape & Kolm 2014).

Based on these theoretical and practical significances of working time issues, scholars are endeavored to detect the relationship between work hours and environmental impacts, and generally yield significant correlations through various methodologies and sampling countries. However, they always use static techniques and group developed economies as sample, and further, correlations may be changed along with different research periods. In response to these drawbacks, in this study, we test the relations by using dynamic approaches, and examining effect of working time on environmental impacts among Western, Southern and Northern European countries.

This article contributes to these issues as well as the larger literature on working time, climate change and sustainable development by empirically assessing the effect of working hours on carbon emissions under various approaches.

The reminder of this article is structured as follows. Section 2 gives a brief review of related empirical literature. Section 3 present a brief introduction of annual working hours, GDP per capita and environmental indicators (carbon emission and energy consumption) for EU-15. Section 4 provides a description of the econometric methodologies and data used. Section 5 proves the existence of significant relationship between working time and environmental pressure. Finally, Section 6 concludes.

4.2 Literature review

Although articles on working time are not rarely-seen in related literature, however, empirical evidences on the relationship between working time and environmental impact have been weak. To our knowledge, five academic publications have already made initial attempts in this area by various methods on different cross-national levels, summaries of the literature review are listed in **Table 4-1**.

Schor (2005) first raised a new path of consumption stability by reducing working hours. In order to justify her assumption, a linear multiple regression of the national ecological footprint for the 18 OECD countries is applied, and results show that significant positive correlations between working hours and environmental degradation do exist.

After that, Rosnick & Weisbrot (2006) detected the possible changes of environmental impacts by shifting the working time regime of U.S. to EU-15 or the other ways round by examining the relationship between working time and energy consumption among 25 economies. Results revealed that if the U.S. follow the EU-15 in terms of working time, then 20% energy consumption will be saved, equivalent to 3% less carbon emission in 2002 than it did in 1990; conversely, if EU-15 countries had worked as many hours in 2003 as that in the United States, then 18% more energy would be consumed.

What is worth noting, they also pointed out that the net effect of work hours on energy use was not determined since increased (decreased) working hours may change life behavior and leading to complex relationship between work-time and energy consumption. In response to this issue, they estimated the correlation of energy efficiency (as measured per working hours) and working time increase by multivariate regression analysis, and the findings showed that a 1% increase in working time lead to a 0.32% increase in energy use, holding others factors unchanged.

By using ecological footprint as environmental indicator, Hayden & Shandra (2009) employed multivariate regression analysis to examine correlations between ecological footprint and working time among 45 countries around the world. Not surprisingly, positive and significant correlations were revealed even when controlling for some relevant variables such as the employment to population ratio and labor productivity. Nässén et al. (2009) conducted an analysis on Sweden, using cross-sectional data to explore the effect on expenditures through changing income (the income effect) and time use patterns (the time effect). The central estimation of this study was that for the total effect (income effect plus time effect), a decrease in working time by 10% reduced energy use and GHG (greenhouse gas) emissions by about 8% on average, and energy use changes with work hours was dominated by income effect.

Later, based on economic de-growth theory for developed countries on working time issues, Knight et al. (2013) examined the effects of working hours on three typical environmental indicators (i.e. ecological footprint, carbon footprint and carbon dioxide emission) by the first-difference panel regression on 29 OECD countries respectively. Findings revealed the significant and positive relationship between working hours and environmental pressures, except for interact with carbon footprint and carbon dioxide emissions when set GDP per capita as control variable. Based on this result, the authors suggest that working time reduction policies may contribute to environmental sustainability.

Based on the literature review noted above, the empirical results are similar despite of minor differences in period of research, sampling countries or methodologies employed. This strongly supports the statically significant correlations between working hours and environmental pressure. Yet, all the research approaches are static and therefore cannot capture dynamic variations between the variables. Moreover, it would be more persuasive by involving larger country-level research samples, and more details on the relationship between different country groups can be detected thereafter.

4.3 Comparisons of Northern, Western and Southern Europe

Fig.4-1 compares the average working time in Northern, Western and Southern Europe over 1970 – 2010, with working hours on the vertical axis and the year on the horizontal axis. Obviously, all the average annual working hours per worker in the three regions are decline with time, indicating an overall decreasing trend in working time for Europe as a whole. Specifically, Southern Europe holds the longest working hours, stagnate in the 1990s and then showing a faster decline tendency. Working hours in Northern Europe are invariably higher than Western counterparts across the whole periods, they were once intersected at 1975 but divergence became larger thereafter, with 1500 h to Western countries in 2010, compare to 1635 h for Northern ones. **Fig.4-2** reports the average GDP per capita for Northern, Western and Southern Europe respectively. In general, GDP per capita of all the three regions are illustrating upward trend during the research period with a similar ratio. However, Southern countries showed a significant gap compared to Northern and Western ones all the time, manifesting its comparatively weaker economic strength. Performances of Northern and Western Europe were much similar, GDP per capita of Northern Europe followed Western counterparts along the research period but never surpassed, with the most closet point occurs in 2005, and then disparity enlarged in the following years. Moreover, according to the mentioned above, we find an interesting relation: the higher economic development level, the lower annual working hours per worker is. This may reveal a law in the evolution of society, that is, economics developed along with decreasing working hours.

Variations of carbon emission and energy consumption among Northern, Western and Southern Europe from 1970 to 2010 are plotted in **Fig.4-3** and **Fig.4-4**, respectively. As can be observed, carbon emission of Western Europe and Northern Europe gradually decreased, while Southern Europe showed increasing trend until 2005. After that, carbon emissions dropped substantially. Generally speaking, Western European countries are the largest emitter in Europe, followed with Southern Europe who exceeded Northern European countries since 1978. Likewise, Western European countries are the largest energy consumer and keep enhancing across the whole period; member states in Northern Europe always increase its energy demand gradually but still the smallest demander in the average sense; energy consumption in Southern Europe surpassed Northern countries since 1987 and experienced a great fall in 2005. All in all, Western countries are more industrialized and therefore consume more and emit more. Energy consumption keeps rising while carbon emission keeps decreasing. The underlying reasons may be lie in the "carbon leakage" (Paroussos et al. 2014) and "rebound effect" on account of the increasing of energy efficiency and technology progress (Shao et al. 2014). Performances in Northern parts are relatively stable with carbon emission gradually fall and energy consumption gradually rise; Southern Europe witnessed remarkable rise and fall during the period, no matter for carbon emission or energy use, indicating its relative vulnerability facing external impact.

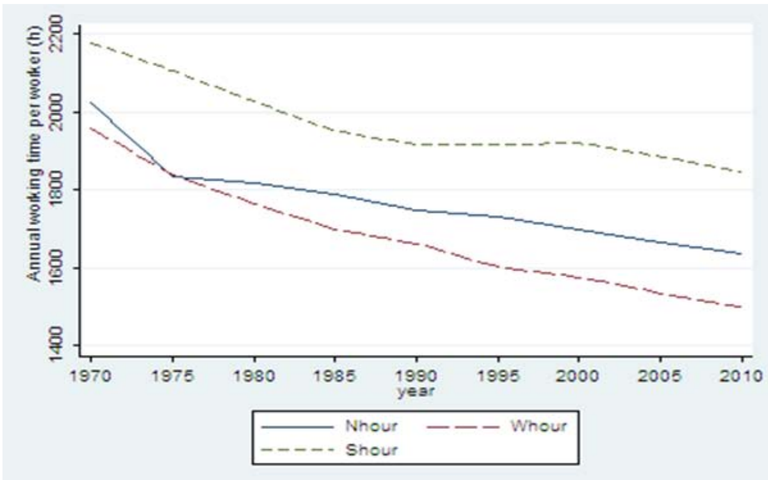


Fig.4-1. Comparison of average annual working time per worker for Northern, Western and Southern Europe

Source: TCB (2016)

Fig.4-2. Comparison of average GDP per capita for Northern, Western and Southern Europe

Source: World Bank (2016)

Fig.4-3. Comparison of average carbon emission for Northern, Western and Southern Europe

Source: World Bank (2016)

Note: CO_2 emissions of Western Europe are not reported due to unavailability of Germany's data.

Fig.4-4. Comparison of average energy consumption for Northern, Western and Southern Europe

Source: World Bank (2016)

4.4 Method and data

4.4.1 Method

Several empirical studies use a panel approach to analyze working time and environmental pollution relations by involving a large number of periods. They use "static" panel techniques and do not incorporate any temporal dependency (lags) of the dependent variable. However, environmental indicators (carbon emission, energy use, etc.) always strongly correlated over time. Therefore, in order to control for the dynamics of the process and test whether significant correlations still explicitly exist in this new framework, we employ dynamic panel technique which contain one or more lagged dependent variables in this analysis.

Generalized Method of Moments (GMM) is a semi-parametrically efficient estimation method and attracted numerous attentions among various disciplines since its large sample properties were established by Hansen (Hansen & Singleton 1982). To date, two GMM approaches are widely used: difference GMM and system GMM. The former is proposed by Holtz-Eakin et al. (1988) and Arellano & Bond (1991), they use lagged level observations as instruments for differenced variables; the latter is putted forward by Blundell & Bond (1998), who utilize both lagged level observations as instruments for differenced variables and lagged differenced observations as instruments for level variables. In other words, system GMM is based on the modification of difference GMM and the estimator includes lagged levels as well as lagged differences. Yet, the validity of difference GMM prone to be weakened by the "weak instruments" problem, that is, when explanatory variables are persistent over time or dependent variable follows a random walk (Blundell & Bond 1998), biased outcomes may arise. What's more, small time dimension of the sample can also generate poor instruments. Therefore, considering these pitfalls of difference GMM, coupled with the perceived information over time and between countries in system GMM, we choose system GMM approach to be the main research tool in this study.

The empirical model that we analyze is:

$$y_{i,t} = \alpha y_{i,t-1} + \beta X_{i,t} + \mu_i + \varepsilon_{i,t} \qquad (1)$$

with $\mu_i \sim i.i.d(0, \sigma_{\mu_i})$, $\varepsilon_{i,t} \sim i.i.d(0, \sigma_{\varepsilon})$.

In this model, dependent variable y stands for environmental pressure, that is, carbon emission and energy consumption in our analysis. $y_{i,t-1}$ is the lagged dependent variable, here we choose first order of time lag as the independent variable. $X_{i,t}$ is a vector of independent variables which consists of the most determinant factors in our regressions and the most commonly used control variables in the work-time literature, μ_i denotes unobserved country-specific fixed effect remain constant over time, and $\varepsilon_{i,t}$ is unobserved White-noise disturbance with $E(\varepsilon_{i,t}) = 0$ for all i and t .

4.4.2 Data

In reference to the often-employed explanatory variables in the literature (Nässén et al., 2009; Knight et al., 2013), we specify explanatory variables under the STIRPAT (stochastic impacts by regression on population, affluence and technology) model, a multivariate non-linear model builds upon the classical IPAT (I = PAT) model (Wei 2011). Originally, the IPAT accounting model describes environmental impacts (I) as a multiplicative function of population size (P), affluence (A) represented by per capita consumption or production, and technology (T) as environmental impacts per unit of consumption or production. Yet, environmental impacts and drivers in this model can only be varied by the same proportion, and thus cannot be able to reflecting non-linear changes. Corresponding to this issue, Dietz and Rosa (1997) proposed the STIRPAT model, which exploring hypotheses regarding the effects of population, affluence, technology and other factors on environmental pollutions. The basic specification of STIRPAT can be expressed as follows:

$$I_i = aP_i^b A_i^c T_i^d e_i \qquad (2)$$

With *I, P, A, T* stand for environmental pressure, population, affluence and technology respectively. Moreover, "a" scales the model, "b", "c" and "d" represent exponents of *P, A* and *T*, "*e*" is error term, and the subscript "*i*" denotes observational units of various indicators among different countries over year. Obviously, in the case of a = b = c = d = e =1, IPAT model regained, indicating that IPAT model is a special case of STIRPAT model. Importantly, it is noteworthy that meanings of technology (T) has changed in that technology is deterministic in IPAT while in STIRPAT it is implicitly assumed depending on population (P), affluence (A) and other driving forces, and this is also the most striking difference between the two models (Wei 2011). Therefore, we include "*T*" in the error term. Follow in this vein, we modify Equation (2) by logging the variables and yield the following equation:

$$Ln(I) = Ln(a) + bLn(P) + cLn(A) + Ln(e) \qquad (3)$$

Coefficients of Eq.(3) after regression indicating the elasticity between explanatory variables and dependent variable, that is, the percentage changes of dependent variable corresponding to 1% increase of independent variables, hold others fixed. Coefficients may be positive (meaning positive effect), or negative (meaning negative effect).

Although several prior studies highlighted the importance of ecological footprint as a proxy for environmental pressures (Knight et al. 2013), considering the fierce controversies on the effectiveness and availability of ecological footprint (van den Bergh & Grazi 2014; Wackernagel, 2014). In this study, we employ country-level total carbon dioxide emission to represent for environmental pressure (*I*), the data are obtained from the World Development Indicators (WDI) of the world bank database, measured in thousand metric tons of carbon dioxide equivalents including those produced during consumption of solid, liquid, and gas fuels and gas flaring. Total population representing *P* are count all residents regardless of legal status or citizenship, collected from the World Bank. With regard to affluence (*A*), we use GDP per capita for the measurement, and decompose it into three components to examine the effects of working time on dependent variable, i.e. annual working time per worker, GDP per hour and employment-to-population ratio, following the methods utilized by Hayden & Shandra (2009) and Knight et al. (2013). To be specific, annual working time per worker is the aggregate number of hours actually worked as a worker or a self-employed person during the accounting period and when their output is within the production boundary; labor productivity is measured as GDP per hour of work in 2013 USD adjusted for purchasing power parity (PPP); and the employment to population ratio measured as the percentage of workers to the population. All the data of the three variables are from The Conference Board Total Economy Database (TCB 2016). Besides, in purpose of extending the limitation of driving forces on population, affluence and technological level, we use percentage of urban population ratio from WDI of the World Bank (2016) to detect the effects of urban population on the environment. All variables are logged in purpose of eliminating heterogeneity bias.

4.5 Empirical results

4.5.1 Dynamic Panel Regression

Dynamic panel regression results for the EU-15 as a whole and Northern, Western and Southern Europe separately are shown in **Table 4-1**. We are aiming to examine the relationship between working time and environmental indicators by sys-GMM approach in a multivariate analysis. As can be seen, the regression results for the lagged dependent variables all showing strong positive relations at 1% significant level, re-affirm our assumption that carbon emission and energy consumption are temporally correlated indicators.

According to prior studies of Hayden & Shandra (2009) and Knight et al. (2013), we disaggregated GDP per capita into three components: annual working hours per worker, labor productivity (GDP per hour) and the employment to population ratio. Working hours shown strong positive correlation with carbon emission at 1% significant level and energy consumption at 5% significant level, which means one percent decrease of working hours lead to 0.35% decline for carbon emission and 0.13% decline for energy consumption, hold other things fixed. This outcome is well fitted to our initial assumptions. Yet, conditions among the three separate regions are somewhat different. To be specific, annual working hours per worker in Western Europe manifest significant positive relations to carbon emission at 10% significant level and 1% significant level to energy consumption. Correlation in Southern Europe is positive and significant at 5% level when interacts with carbon emission, but not significant for energy use. As for Northern Europe as a whole, significant correlations were not found despite its positive relation with carbon emission and energy consumption. Above all, working hours were found to be positively related to environmental pressures for all EU-15 countries, supporting the argument that environmental demands and impacts could be reduced by decreasing working time. For the three separate regions, Western Europe shows the most significant relations, followed by Southern Europe with 5% significant level to carbon emission, and Northern countries holds positive but non-significant correlation between working time and environmental impacts.

Labor productivity was found to be positive and significant in most cases, implying that increased labor productivity induced by technology advancement may enhance energy use and carbon emission significantly. This in turn indicates the existence of “rebound effect” or “Jevons Paradox” in Europe in the past decades. However, working time in Northern Europe still non-significantly correlated with environmental degradations, and the same situation applied to carbon emission in Western Europe. With regard to the employment to population ratio, no significant correlations were found in all the cases, which means environmental burdens exerted by workers at workplace and non-workers in the leisure time are not remarkably different. What's more, negative relation occurs when interacts with energy use for EU-15 despite its non-significant level, implying an initial appearance of "rebound" phenomenon through which energy use may re-enhanced due to the increasing leisure time (Nässén et al. 2009). This finding is contrary to the results of Knight et al. (2013) that employment to population ratio has a positive and significant impact on total carbon emissions, the difference may be come from the data and methodologies employed, our data are encompass EU-15 countries and use sys-GMM approach which reflecting dynamic variation in the long run.

The regression results for the control variables are generally consistent with other studies (Hayden & Shandra 2009; Knight et al., 2013). Percentage of trade in GDP was found to be significant only in interaction with energy consumption in Southern Europe. Percentage of gross capital formation in GDP shows positive significant relations with environmental pressures for EU-15 and Southern Europe, as well as carbon emission in Western Europe. This can be explained by the fact that capital has profound effect on the environment through investment in the long run, especially for the relatively less well-off Southern European countries who have more reliance on capital for further development. Both the population and percentage of urban population variables were appeared as strong positive determinants of environmental pollutions at various significant levels, which implies that absolute population growth and percentage of urban population growth in the process of urbanization all pose negative impacts in a long term point of view.

Table 4-1. Dynamic regression results for EU-15 and the Northern, Western and Southern Europe respectively.

Items	**Panel regression results**		**Dynamic regression results in Northern, Western and Southern Europe**					
			Northern Europe		Western Europe		Southern Europe	
Dependent Variables	Carbon Emissions	Energy Consumption	Carbon Emissions	Energy Consumption	Carbon Emissions	Energy Consumption	Carbon Emissions	Energy Consumption
LAG	0.8978*** (0.014)	0.8896*** (0.015)	0.8463*** (0.032)	0.8804*** (0.035)	0.9137*** (0.025)	0.8808*** (0.022)	0.9230*** (0.031)	0.8508*** (0.036)
Annual working Hours Per Worker	0.3483*** (0.088)	0.1322** (0.060)	0.2298 (0.176)	0.1569 (0.115)	0.2850* (0.152)	0.3712*** (0.116)	0.3071** (0.141)	0.0732 (0.105)
Labor Productivity	0.0692*** (0.023)	0.0627*** (0.016)	0.0617 (0.045)	0.0362 (0.029)	0.0470 (0.043)	0.1190*** (0.032)	0.0966** (0.040)	0.1465*** (0.036)
Employment to population ratio	0.0299 (0.043)	-0.0118 (0.0291)	0.0622 (0.110)	0.0679 (0.070)	0.0275 (0.050)	0.0136 (0.037)	0.0506 (0.058)	0.0875 (0.0561)
Trade (%)	-0.0012 (0.0214)	-0.0045 (0.014)	-0.0567 (0.045)	-0.0060 (0.027)	0.0123 (0.030)	0.0051 (0.022)	-0.0506 (0.031)	-0.0553** (0.024)
Capital Formation (%)	0.0508** (0.024)	0.0579*** (0.016)	0.0022 (0.049)	0.0125 (0.030)	0.0777** (0.039)	0.0339 (0.028)	0.0920*** (0.029)	0.0852*** (0.022)
Population	0.0703*** (0.015)	0.0915*** (0.014)	0.1310*** (0.034)	0.0796*** (0.031)	0.0691*** (0.021)	0.1130*** (0.021)	0.0697** (0.034)	0.1207*** (0.036)
Urban Population (%)	0.1294** (0.060)	0.1807*** (0.047)	0.0410 (0.129)	0.2115** (0.09)	0.1583 (0.077)	0.0749 (0.056)	-0.0098 (0.082)	0.1308* (0.073)
Cons	-3.4913*** (0.879)	-2.4560*** (0.650)	-2.1829 (1.640)	-2.1840* (1.169)	-3.3606** (1.454)	-4.1758*** (1.145)	-2.9123** (1.410)	-1.9771* (1.024)

4.5.2 Phased dynamic regressions

In this section, we divide the whole research period into two phases, 1970 – 1990 and 1990 – 2010, to discover the changes of relationship between working time and environmental pressures from the former 20 years to the latter 20 years. **Table 2** reports the dynamic regression results for carbon emission as dependent variable. Not surprisingly, all lagged carbon emissions show significant and positive relations at 1% level.

As can be observed, relationship of working time and carbon emissions in Northern Europe converts from negative to positive although not significant. This is consistent with our previous finding that correlations in Northern countries are not significant. Opposite situation occurs in Western Europe, with the relationship changed from positive to negative, but all in significant levels. The underlying causes of this "rebound" phenomenon may lie in the fact that more leisure time may encourage energy-intensive activities such as car travel and vocation abroad in the case that these countries became more and more wealthier, through which carbon emissions re-increased (Nässén et al. 2009). This finding is consistent with the argument framed by Druckman et al. (2012), that a simple transfer of time from paid work to the leisure may be employed in more carbon intensive way. Nørgård (2013) also pointed that "leisure time does not guarantee a lower environmental impact", and "the extra leisure time will tend to require more energy, but the amount will depend on how leisure is spend", which is one of the possible ways reduced hours affects energy consumption and other environmental impacts. Besides, Southern Europe witnessed a conversion from non-significant to significant with positive correlations. Labor productivity in Northern Europe is positive and non-significant throughout the two periods, in line with the research outcomes noted above. Conversely, situations in Southern counterparts are positive and significant at 5% level, confirming the existence of "rebound effect". What is worth noting is that relationship in Western Europe shift from positive to negative at 5% and 1% significant levels respectively, illustrating that member states in Western Europe may jump out of the rebound trap to some extent and showing a virtuous circle of technology progress and environmental condition. In general, the variable of employment to population ratio shows no significant sign to carbon emission, exception lies in the Southern Europe with the transformation from positive and significant to negative and non-significant relationship. With regard to control variables, significant relation turns toward non-significant in Northern Europe for percentage of trade in GDP. The variable reflecting percentage of gross capital formation in GDP became significant in the latter 20 years for Western and Southern Europe, showing the increasingly dominate role for capital to carbon emissions. The impacts of population to the environment were enhanced in all the three areas through two periods, with an increase of coefficient for Northern and Southern Europe, and an augment of significant level for Western Europe. By contrast, effects of urban population ratios to the environment are remarkably declined, with a conversion from positive to negative for Northern Europe, and significant to non-significant for Western and Southern Europe. The implication of this finding is that environmental impacts of urban populations were declined while rural residents were playing an increasingly significant role to the environmental degradation.

Phased dynamic regressions for energy consumption are showing in **Table 4-3**. Similar to estimated regressions for carbon emissions, working hours in Western countries turned from positive to negative in significant levels, reflecting a "rebound" phenomenon noted previously; correlations in Southern countries turned toward significant in the latter 20 years. However, somewhat differently, correlation in Northern countries became significant in the second phase, indicating that energy consumptions are more closely related to working time for member states in Northern Europe, in comparison to carbon emissions. For labor productivity in the latter phase of Western countries, inkling of negative relation appears although not significant yet; situations in Northern and Southern parts remain unchanged. Nevertheless, their employment to population ratio changed from positive and significant in the first phase to non-significant in the second phase, indicating a faded role of employers to the environmental impacts, compare to residents without a job such as elders, children and the unemployed population. In addition to these, percentage of trade in GDP became un-significant in Northern Europe whilst other two areas remain unchanged on the whole; percentage of gross capital formation in GDP for Western and Southern states transferred to be significant which manifesting that energy use became increasingly prone to be affected by capital. Situations of population and urban population ratio are extremely similar to the cases of carbon emission: correlations of population and energy consumption in the three distinct areas strengthened while relations for the urban population ratio counterparts loosed, implying the dramatically enhanced status of rural inhabitants on energy use.

Table 4-2. Phased dynamic regression for carbon emission as dependent variable over 1970 – 2010.

Dependent variable: Carbon emission	**1970 – 1990 regression**			**1990 – 2010 regression**		
	Northern Europe	Western Europe	Southern Europe	Northern Europe	Western Europe	Southern Europe
LAG	0.7931*** (0.059)	0.8435*** (0.049)	0.7682*** (0.055)	0.5430*** (0.074)	0.8329*** (0.047)	0.7156*** (0.086)
Annual working Hours Per Worker	-0.0041 (0.264)	0.7539*** (0.268)	0.1830 (0.262)	0.1972 (0.465)	-0.5297** (0.222)	1.1124*** (0.305)
Labor Productivity	0.0157 (0.073)	0.1901** (0.093)	0.1421** (0.069)	0.1003 (0.1346)	-0.2646*** (0.096)	0.2123** (0.102)
Employment-population ratio	-0.3586 (0.245)	0.2399 (0.272)	0.4506*** (0.103)	0.2351 (0.299)	0.1221 (0.083)	-0.0763 (0.129)
Trade (%)	-0.1765*** (0.066)	-0.1009 (0.078)	-0.0637 (0.048)	-0.1540 (0.096)	0.0421 (0.041)	0.0061 (0.052)
Capital Formation (%)	0.0726 (0.058)	0.0649 (0.075)	0.0535 (0.042)	0.0178 (0.093)	0.0974* (0.052)	0.2835*** (0.053)
Population	0.1828*** (0.056)	0.0920** (0.047)	0.1965*** (0.063)	0.2989*** (0.062)	0.1240*** (0.037)	0.3120*** (0.093)
Urban Population (%)	0.2709 (0.260)	0.3902** (0.174)	0.4058** (0.188)	-0.4666 (0.333)	0.0939 (0.124)	-0.0757 (0.153)
Cons	-1.5459 (2.542)	-7.2035*** (2.663)	-3.6035 (2.614)	1.3711 (4.337)	4.0878** (2.033)	-11.6831*** (3.243)

Table 4-3. Phased dynamic regression for energy consumption as dependent variable over 1970 – 2010.

Dependent variable: Energy consumption	**1970 – 1990 regression**			**1990 – 2010 regression**		
	Northern Europe	Western Europe	Southern Europe	Northern Europe	Western Europe	Southern Europe
LAG	0.8320*** (0.051)	0.8511*** (0.038)	0.6588*** (0.068)	0.8366*** (0.064)	0.7604*** (0.051)	0.6907*** (0.085)
Annual working Hours Per Worker	0.2765 (0.213)	0.5104** (0.201)	-0.2683 (0.196)	0.5337* (0.295)	-0.2743* (0.166)	0.5590*** (0.174)
Labor Productivity	0.0924 (0.059)	0.2152*** (0.058)	0.2015*** (0.065)	-0.0138 (0.083)	-0.0688 (0.072)	0.1946*** (0.069)
Employment-population ratio	0.3551** (0.180)	0.0485 (0.202)	0.5152*** (0.103)	0.1245 (0.178)	0.0539 (0.058)	-0.0756 (0.099)
Trade (%)	-0.0247 (0.047)	-0.1296** (0.055)	-0.0762* (0.041)	0.0263 (0.058)	0.0613** (0.031)	0.0623** (0.030)
Capital Formation (%)	0.0066 (0.042)	-0.0290 (0.057)	0 .0684** (0.034)	0.0031 (0.051)	0.0998*** (0.037)	0 .2043*** (0.032)
Population	0.1374*** (0.052)	0.1060*** (0.035)	0.2902*** (0.073)	0.1254** (0.052)	0.2150*** (0.046)	0.3127*** (0.085)
Urban Population (%)	0.1190 (0.170)	-0.0340 (0.170)	0.5039*** (0.151)	0.4332** (0.190)	0.0240 (0.083)	0.1265 (0.121)
Cons	-2.9639 (2.054)	-3.8403* (2.302)	-1.3884 (1.948)	-6.0978** (2.706)	0.7741 (1.599)	-8.2754*** (2.169)

4.6 Concluding remarks

Methodology employed in this study provides two improvements upon previous seminal works. The first, we used a system GMM dynamic analysis framework, which allows us to capture certain cumulative dimensions of working hours' impact on environmental pollution. This method takes into account these aspects that were ignored by static techniques, such as environmental degradation caused by long-term working time policy, or the effects of population and urban population ratio on future environmental pressures. The second aspect of our study that improves on previous work is that we avoid the controversial ecological footprint indicator, and use energy consumption as complement index of carbon emission. In addition to that, we divide EU-15 into three widely-recognized areas (Northern Europe, Western Europe and Southern Europe) with different socio-economic contexts, detect and compare their correlations of working time and environmental damages which are able to provide detailed information of interest, as well as further understandings of worktime-environment nexus in Europe in the past four decades.

5. Does decreasing working time reduce environmental pressures? New evidence based on dynamic panel approach

5.1 Introduction

The growing attention on working time issues in academic communities and policy arenas is related to a close association with themes of utmost relevance to society, such as income inequality (Bowles & Park 2005), labor markets (Prescott et al., 2009; Chang et al., 2011), and well-being (Pouwels et al., 2008; Becchetti et al., 2012). The perspectives and theories on working time are extremely diverse (Perlow 1996; Hermann 2015) and, far from tackling them in a comprehensive manner, this paper modestly focuses on the environmental aspects.

York et al. (2005, p.150) observed that "to be successful in reducing human pressure on the environment, efforts to improve the efficiency of production likely need to be coupled with other policies directed at the ultimate driving forces of production", working time reduction (WTR) being one of such policies. Thus, as explained below, the effects of less working hours on environmental degradations were increasingly debated in the past decades. This discussion was also strongly entering the climate change agenda worldwide, as the use of time has clear implications in terms of energy consumption and carbon emissions (Druckman et al., 2012; D'Alisa & Cattaneo 2013).

Additionally, Jackson (2009) regarded working time policies as essential because production processes are bounded by ecological limitations. In relation to this, WTR policy played a key role in the de-growth agenda, which "involves a socially sustainable process of strategic downscaling in material throughput" (Knight et al., 2013, p.693). Supporters of socially sustainable de-growth putted proposals of WTR forward (e.g., the four-day workweek), in order to simultaneously improve employment conditions and abate environmental pressures (Kallis 2013; Ashford & Kallis 2013). This debate gathered momentum, especially after the 2008 global crisis.

In practice, WTR policies were extensively enacted in countries like Japan, France and Denmark since the 1990s, among inter alia (Kuroda 2010; Askenazy 2013). Such policies, which are worth deeper analysis, differed remarkably according to their unique socio-economic contexts and show different effects on economic growth, leisure activities, and happiness (Schreiber 2008; Kuroda 2010; Grape & Kolm 2014).

Based on the theoretical and practical relevance of working time issues, scholars were endeavored to detect the relationship between working hours and environmental impacts, and generally yielded significant correlations through various methodologies and sampling countries. As elaborated in the next section, prior attempts focused on the use of static techniques – such as multivariate regression and first-difference panel regression – and most of them took data from developed economies as the empirical source of evidence. Moreover, correlations were likely to change with respect to different research periods.

In accordance with these limitations, this study aimed at contributing to the literature in two ways. On the one hand, we examined the effect of working time on environmental impacts by using dynamic approach. On the other hand, we also tested the interaction effects of two time periods among two country groups. Additionally, this article feeds the intellectual debate on working time and climate change by empirically assessing the effect of hours of work on CO_2 emissions under a dynamic approach.

The paper is structured as follows. Section 2 overviews related empirical literature. Section 3 provides a description of the econometric methodologies and data used. Section 4 deepens prior studies by presenting the correlations among separated time periods. Finally, section 5 concludes.

5.2 Literature review

Since the seminal works by Schor (1995) and Hayden (1999) that connected working time and environmental pressures, several empirical studies addressed the linkages between hours of work and environmental impacts. Looking at recent examples, Devetter & Rousseau (2011) analyzed this link through a wealth effect and changes of life-style and consumption patterns induced by a reduction in working time. Hayden & Shandra (2009) and Knight et al. (2013) illustrated both the scale effect and compositional effect, in which the former indicated the changes of economic size whereas the latter related to the composition of resource consumption. Meanwhile, Nässén et al. (2009) and Nässén & Larsson (2015) focused on the household allocation of time and resources and shaped consumption patterns by using income effect and time effect. From these examples we noticed that correlation analysis generally corresponds to one of the two types of data source, i.e. household micro-data analysis and national summary statistics. In this light, we summarized previous contributions from the literature following this classification (**Table 5-1**).

5.2.1 National summary statistics

Most of the reviewed empirical analyses were undertaken at country-level. In this respect, to simulate environmental and social indicators of a given growth pattern using the econometric input-output PANTA RHEI model, Spangenberg et al. (2002) demonstrated that reduced working time, together with technology innovation, social security system, and green taxes, were essential determinants for guaranteeing the combination of competitive economy, low unemployment rate and lower environmental pressures. Empirical work by Schor (2005) raised the possibility of a new path of consumption stability by reducing working hours. In order to justify her assumption, a linear multiple regression of the national ecological footprint for the 18 OECD countries was applied, and results proved a significant positive relationship between working hours and environmental degradation.

Soon after that, Rosnick & Weisbrot (2006) detected possible changes of environmental impacts from shifting the work-time regime of the U.S. to that of the EU-15, or vice versa. They found that if the U.S. followed the EU-15 in terms of work-time, 20 percent energy consumption would be saved, which was equivalent to 3 percent less carbon emission in 2002 than in 1990 levels. Conversely, if EU-15 countries had worked as many hours in 2003 as did workers in the United States, then 18 percent more energy would have been consumed. Following this study, and using “illustrative scenarios” from IPCC, Rosnick (2013) estimated the impact on global warming of reducing work hours over the rest of the century by an annual average of 0.5 percent, and this change would eliminate about one-quarter to one-half of the warming caused by 1990 levels of greenhouse gas (GHG) concentrations already in the atmosphere.

However, the net effect of work hours on energy use was not determined since increased (or decreased) hours of work may change life behavior, leading to complex relationships between work-time and energy consumption. In response to this issue, Rosnick & Weisbrot (2006) tried to estimate the correlation of energy efficiency (measured per hours worked) and work-time increase by multivariate regression analysis. Findings showed that a 1 percent increase in working time leads to a 0.32 percent increase in energy use, holding other factors unchanged. Using an ecological footprint as an environmental indicator, Hayden and Shandra (2009) also employed multivariate regression analysis to examine correlations between the ecological footprint and hours of work among 45 countries. Again, a significant positive relationship was found even when controlling for the employment-to-population ratio, labor productivity and other relevant variables.

In an attempt to build propositions about working time for developed countries that are coherent with the sustainable de-growth theory, Knight et al. (2013) examined the effects of working hours on three typical environmental indicators, namely ecological footprint, carbon footprint and CO_2 emissions. Using the first-difference panel regression on 29 OECD countries for each one of these indicators, they unveiled significant and positive relationships between working hours and environmental pressures in most models. A recent research conducted by Fitzgerald et al. (2015) advanced WTR studies and again confirmed the increasing effects of working hours on energy consumption both in developed and developing nations. Based on similar results, these scholars advocated for WTR policies to promote environmental sustainability.

5.2.2 Household micro-data analysis

The WTR literature has also developed at the household micro-data level. Nässén et al. (2009) conducted an analysis focused on Sweden, using cross-sectional data to explore the effect on expenditures from changing income (the income effect) and time-use patterns (the time effect). Result showed that, for the total effect (income effect plus time effect), a decrease in work-time of 10 percent reduced energy use and GHG emissions by about 8 percent on average. The change of energy uses with working hours was dominated by income effect. Nässén & Larsson (2015) collaborated again to further analyze time use and consumption patterns of Swedish households, examining the effects of changing income and availability of leisure time. The estimates basically matched their former results, confirming the dominant role of income effect. Additionally, they sketched a scenario that forecast a gradual reduction towards 30 work-hours per week in year 2040 that would significantly slow the growth of energy demands in the long run.

In order to detect whether longer work-time has an impact on environment, Devetter & Rousseau (2011) undertook surveys on French household expenses in order to analyze the direct link between working hours and the environment, which was backed up by two distinct but complementary phenomena. The first was the wealth effect, i.e. longer working hours have an impact on income, which itself pushes consumption upwards, contributing to environmental degradation. The second focused on the changed life-style and consumption pattern induced by working hours. Results confirmed the energy-intensive consumptions and unsustainable lifestyles induced by long working hours.

Alternatively, by focusing on unpaid household work and using time as the metric of reference instead of money, D'Alisa & Cattaneo (2013) proposed that the continual shift of labor and skill from household production to the market economy would lead to a more intensive use of energy, through analyzing the use of time in Catalonia across gender and age categories. Thus, reallocation of services and goods from the market to the household was necessary for a low energy-demanding future, and work-sharing at household level and co-housing at neighborhood level were essential ways to balance unpaid workload and reduce energy use.

The remarkable effort undertaken in the empirical research background confirms the significant correlations between working hours and environmental pressures across differences in periods of research, sampling countries and methodologies employed. Yet, the static research approaches presented above could hardly capture dynamic variations between the variables, which raised the question of whether this result would also be supported by dynamic approaches. Moreover, policy messages are believed to be more persuasive if different time periods and larger country-level research samples are involved in the empirical analysis. Consequently, this helped us to frame the study.

Table 5-1. Summary of literature review on empirical evidences of working time and environmental pressures in chronological order.

Author(s)	Environmental indicators	Methods	Data Structure	Type of data source	Main Results
Spangenberg et al. (2002)	carbon emission; material inputs	PANTA RHEI model	Germany; 1994-2000	national summary statistics	Reduced working time (along with other process) was needed to attain economic competitiveness, low unemployment and to ease environmental pressures
Schor (2005)	Ecological footprint	Linear multiple regression	18 OECD countries; -	national summary statistics	Significant and positive correlations between working hours and ecological footprint.
Rosnick & Weisbrot (2006)	Energy consumption	Scenario analysis; multivariate regression analysis	48 countries; 2003-2005	national summary statistics	Expanded energy use due to the increase of economic production and consumption caused by rising working hours.
Hayden & Shandra (2009)	Ecological footprint	Structural equation model	45 countries; 2000	national summary statistics	Significant positive relationship demonstrated even when controlling for the employment-to-population ratio, labor productivity and other control variables.
Nässén et al. (2009)	Energy use; Greenhouse gas (GHG) emission	Micro-data approach; Linear regression	Sweden; 2006	household micro-data analysis	10 percent increase (or decrease) in work hours induces changes in energy use and GHG emission (8 percent on average)
Devetter & Rousseau (2011)	time-saving equipments; house, energy and services	Micro-data approach; Logit model	France; 2001	household micro-data analysis	Longer working hours encouraged intensive consumptions of goods and energy, and favored conspicuous expenditure and non-sustainable lifestyles
D'Alisa & Cattaneo (2013)	Energy demand	Multi-scale integrated analysis of societal & ecosystem metabolism	Catalonia; 2002-2003	household micro-data analysis	Substituting labor and skills from household-based production to the commodity-based economy was dangerous; and the future adaptability might require

		(MuSIASEM)			policies reallocating resources towards the unpaid and the community in terms of de-growth perspective.
Knight et al. (2013)	Ecological footprint; Carbon footprint; Carbon emission	First-difference panel regression	29 OECD countries; 1970-2007	national summary statistics	Work hours were positively correlated with environmental pressures (both in scale effect and compositional effect).
Rosnick (2013)	Greenhouse gas (GHG) emission	Illustrative scenarios; MAGICC	world-wide economies; 1990-2100	national summary statistics	Impact of climate change by reduced work-hours over the rest of the century was averagely 0.5 percent per year. This effect would eliminate about one quarter to one half of the global warming.
Nässén & Larsson (2015)	Energy use; Greenhouse gas (GHG) emission	Micro-data approach; Linear regression; scenario analysis	Sweden; 2006	household micro-data analysis	1 percent decrease of working time may reduce energy use (0.7 percent) and GHG emissions (0.8 percent). Gradual WTR towards 30 hours per week would significantly reduce the growth of energy use.
Fitzgerald et al. (2015)	Energy consumption	Prais-Winsten regression model	52 countries; 1990-2008	national summary statistics	Increased effect of working hours on energy consumption through time for both developed and developing countries.

5.3 Econometric method and data

5.3.1 Econometric method

Previous empirical studies have regularly employed "static" panel techniques. Such techniques do not incorporate any temporal dependency (lags) of the dependent variable, neglecting the fact that environmental indicators (such as CO_2 emission, energy use, and ecological footprint) are likely to correlate strongly over time. Thus, in order to control for the dynamics of the process and test whether significant correlations still explicitly exist under this new framework, we employed a dynamic panel technique which contains lagged dependent variable among the regressors.

The Generalized Method of Moments (GMM) is a semi-parametrically efficient estimation method which, according to Rao et al. (2010), drew attention from various disciplines after its large sample properties were established by Hansen and Singleton (1982). To date, two GMM approaches have been widely used: difference GMM (diff-GMM) and system GMM (sys-GMM). The former was proposed by Holtz-Eakin et al. (1988), Arellano & Bond (1991). They argued that instruments can be obtained if one utilizes the orthogonally conditions that exist between lagged values and the disturbances (Baltagi 2005), and regarded lagged level observations as instruments for differenced variables. The latter was proposed by Blundell and Bond (1998), who utilized both lagged level observations as instruments for differenced variables and lagged differenced observations as instruments for level variables (Doytch & Uctum 2011).

In other words, sys-GMM is based on the modification of diff-GMM and the estimator includes lagged levels as well as lagged differences. Comparatively speaking, the validity of diff-GMM is prone to be diminished by the "weak instruments" problem, that is, when explanatory variables are persistent over time or the dependent variable follows a random walk (Blundell & Bond 1998), then biased outcomes may arise (Felbermayr 2005). Furthermore, the issue of "small time dimension of the sample" contributes to generating poor instruments, over-identification issues can also be tackled through Sargan tests of orthogonality between the instruments and the residuals and through tests of second order residual autocorrelation (Klomp & de Haan 2013). Overall, considering these limitations of diff-GMM, coupled with the perceived advantages regarding information over time and between countries in sys-GMM, we used the sys-GMM approach as the main research tool in this study.

5.3.2 Model specification and data

After looking at the selection of variables in the background literature (Schor 2005; Nässén et al., 2009; Knight et al., 2013), we specified explanatory variables under the STIRPAT (stochastic impacts by regression on population, affluence and technology) model (Wei 2011). This is a multivariate non-linear model stemming from the classical $IPAT$ ($I = PAT$) model (Ehrlich, P. R. and Holdren 1971).

Originally, the IPAT accounting model describes environmental impacts (I) as a multiplicative function of population size (P), affluence (A) represented by per capita consumption or production, and technology (T) as environmental impacts per unit of consumption or production. Yet, environmental impacts (I) and their drivers (i.e. P, A and T) in this model can only be varied by the same proportion, and thus are not able to reflect non-linear changes. As a response to this issue, Dietz and Rosa (1997) proposed the $STIRPAT$ model, which explores hypotheses regarding the effects of population, affluence, technology and other factors on environmental pollutions (Wang et al., 2013; Liddle 2015). The basic specification of $STIRPAT$ can be expressed as follows:

$$I_i = aP_i^b A_i^c T_i^d e_i \qquad (1)$$

where I , P , A and T are environmental pressures, population, affluence and technology, respectively. It is noteworthy that, in a different manner to that described prior to WTR literature, we removed P from the right-hand side and divide I by P. Thus, the environmental indicator in this study would be in per capita terms. This option seems reasonable, as population elasticity does not vary meaningfully according to income level or population size (Liddle 2015). In this respect, O'Neill et al. (2012, p.159) also argued that "if all other effects on emissions are controlled for, and indirect effects of population on emissions through other variables are excluded, population can act only as a scale factor and its elasticity should therefore be 1".

In addition, the meaning of technology (T) is deterministic. The disregard of possible interdependencies between P , A and T is one of the criticisms made of this popular equation

(Alcott 2010). In this respect, technology in *STIRPAT* is implicitly assumed as dependent on population (P), affluence (A) and other driving forces, T is also the most striking difference between the two models (Wei 2011), which entails that " T " is included in the error term. Accordingly, we modify Equation (1) by removing P and logging the variables, which will yield the following equation:

$$Ln(I`) = Ln(a) + bLn(A) + Ln(e) \qquad (2)$$

where $I` = I / P$. Coefficients of Equation (2) indicate the elasticity between explanatory variables and dependent variable, i.e. the percentage changes of the dependent variable corresponding to a one percent point increase of independent variables, holding other variables fixed.

Several prior studies highlighted the importance of ecological footprint as a proxy for environmental pressures (Schor 2005; Hayden & Shandra 2009). However, considering the fierce controversies on the effectiveness and availability of EF (van den Bergh & Grazi 2014; Wackernagel 2014), in this study we employ annual country-level carbon emissions per capita in order to represent for environmental pressure. Data were obtained from the World Development Indicators (WDI), measured in metric tons of carbon dioxide equivalents, including those produced during consumption of solid, liquid, and gas fuels and gas flaring.

We used GDP per capita measured in 2005 USD to estimate affluence (A). Following the methods utilized by Hayden & Shandra (2009) and Knight et al. (2013), GDP can be decomposed into three components in order to examine the effects of working time on dependent variable, i.e. annual working time per worker (Work-time), GDP per hour (Labor productivity) and employment-to-population ratio (Emp. % population).

Specifically, annual working time per worker is the aggregate number of hours actually worked as a worker or a self-employed person during the accounting period and when their output is within the production boundary. Labor productivity is measured as GDP per hour of work in 2013 USD adjusted for purchasing power parity (PPP). Finally, the employment-to-population ratio (Emp. % population) is measured as the percentage of workers with respect to the population. All the data for the three variables were obtained from The Conference Board Total

Economy Database (TCB 2016). We also controlled for the percentage of service to GDP (Ser.% GDP), both import and export (World Bank 2016). All variables are logged with the purpose of eliminating heterogeneity bias.

Besides, two dummy variables (Period1 and Period2) were included to examine the effect of working time on carbon emissions per capita along different research periods. Each of these dummy variables takes the value of 1 if the year falls, respectively, into the periods 1980-2000 and 2001-2010.

For the classification of country types, we considered a country to be developed if it falls within the World Bank (2016) category of high income, and considered a country to be developing if it does not have a high-income economy. We finally obtained 37 developed countries and 18 developing countries. Such distinctions based on income are not rare and appeared in related WTR literature (Fitzgerald et al. 2015), although controversies on the definition still remain as there are varying criteria according to various socio-economic characteristics. Eventually, we collected the data for a time span of 31 years from 1980 to 2010, and for 55 countries from the poorest (Bangladesh) to the richest (Luxembourg).

The basic empirical model that we analyze is:

$$y_{i,t} = \alpha y_{i,t-1} + c_i Time_{i,t} + d_i Labor_{i,t} + e_i Emp_{i,t} + f_i Ser_{i,t} + g_i Ex_{i,t} + h_i Im_{i,t} + \mu_i + \varepsilon_i \quad (3)$$

where subscripts i, t denote the i th cross-section and t th time period, the dependent variable $y_{i,t}$ represents environmental pressure, that is CO_2 emissions per capita in our analysis, $y_{i,t-1}$ is the lagged dependent variable, here we choose the first order of time lag as the independent variable, slope coefficients (c_i, d_i, e_i, f_i, g_i and h_i) are heterogeneous, μ_i denotes unobserved country-specific fixed effect remain constant over time, and $\varepsilon_{i,t}$ is unobserved White-noise disturbance with $E(\varepsilon_{i,t}) = 0$ for all i and t.

Descriptive statistics for all the panel data are displayed in **Table 5-2**, and demonstrate that for both the dependent and independent variables, there is considerable variation across observations. Pairwise correlations for the dependent variable and all the explanatory variables in logarithmic form are reported in **Table 5-3**. The result illustrates two interesting facts: firstly, all the variables are significantly correlated at the 1 percent level; secondly, working time is negatively correlated with carbon emissions per capita, as well as other explanatory variables. These observations highlight the importance of a careful multivariate econometric analysis.

Table 5-2. Descriptive statistics for all variables in this study.

Variables	**mean**	**sd**	**min**	**P25**	**P50**	**P75**	**max**
Carbon p. c.	1.6746	0.8901	-2.3846	1.2737	1.9019	2.2594	3.4105
Work-time	7.5399	0.1337	7.2307	7.4581	7.5329	7.6014	7.9763
Labor productivity	3.0695	0.7933	0.0058	2.6437	3.1771	3.7040	4.4124
Emp. % Population	3.7451	0.1731	3.2474	3.6295	3.7650	3.8776	4.2794
Ser. % GDP	4.0874	0.1933	3.0791	3.9902	4.1221	4.2179	4.4602
Export	24.5011	1.5777	20.7410	23.3387	24.5716	25.7035	28.1417
Import	24.5132	1.5273	20.9584	23.3720	24.5391	25.6566	28.4193

Note: All variables are logarithmized; sd is standard deviation.

Table 5-3. The correlation matrix of all variables in this study.

Variables		1	2	3	4	5	6	7
Carbon p. c.	1	1.00						
Work-time	2	-0.39*	1.00					
Labor pro	3	0.83*	-0.67*	1.00				
Emp. % Popu	4	0.53*	-0.39*	0.49*	1.00			
Ser. % GDP	5	0.34*	-0.51*	0.63*	0.25*	1.00		
Export	6	0.55*	-0.33*	0.57*	0.41*	0.41*	1.00	
Import	7	0.50*	-0.27*	0.51*	0.40*	0.42*	0.98*	1.00

Note: All variables are logarithmized. Correlation is significant at the 0.01 level (2-tailed).

5.4 Empirical analysis

5.4.1 Variation tendency of working time and carbon emissions during 1980-2010.

Fig. 5-1 compares the average carbon emission per capita for developed and developing countries over the period 1980-2010. It is easy to observe that the average carbon emission per capita in developing countries grew during the whole research period, increasing from 3.60 t in 1980 to 4.17 t in 2010. Although average CO_2 emissions per capita in developed countries are invariably more than two-fold those of their developing counterparts, their evolution was more steady, with a slight decrease of emissions in 2010 (9.11 t) compared to the amount for 1980 (9.63 t).

Variations of average annual working hours per worker among developing and developed countries from 1980 to 2010 are plotted in **Fig. 5-2**. Following inspection of the data, and for the purpose of our analysis, we split the research period into two sub-periods. The first period is from 1980 to 2000, when both types of countries show a similar trend. In contrast, the second sub-period spans from 2001 to 2010, which is characterized by a divergence of working time patterns. Thus, year 2000 is the turning point which remarkably accelerated the decline of work-time for developed economies while this increased in their developing counterparts. As can be seen in **Fig. 5-2**, average working time dropped by nearly 83 hours in developed countries (from 1,838.9 h in 2000 to 1,756.17 h in 2010), while gradually increasing by nearly 30 hours in developing countries (from 2,000.02 h in 2000 to 2,029.6 h in 2010).

It is worth mentioning that maximum working week regulations and work-sharing policies were introduced around that time point. For example, France launched work-sharing reform in 2000 and the 35-hour work week was also enacted in the same year, with the aim of unemployment rate reduction and gender inequality reduction (Coote, A., Franklin, J., Simms 2010; Askenazy 2013). South Korea had the fastest declining working time in the OECD countries, due to the implementation of a work-hour limiting regulation issued in 2004 (Park et al. 2012). In addition, the EU's Working Time Directive (2003/88/EC) required EU countries to guarantee workers' rights by a setting minimum number of holidays each year and limiting weekly working hours, which had hastened the declining process (WTD 2003). According to Lee et al. (2007), such reduction may be explained by the increased proportions of female-workers who typically work less hours than male-workers.

Based on prior studies of WTR (Victor 2012; Knight et al., 2013; Nässén & Larsson 2015), we expected that environmental pressures in developed countries will decline while developing countries still bear increasing environmental burdens. In addition, to further investigate the variations over time, we specified year 2000 as the breaking point of the time-use pattern in the following analysis, and examined whether the correlation between hours of work and environmental pressures remain significant before and after 2000, according to the figures provided above.

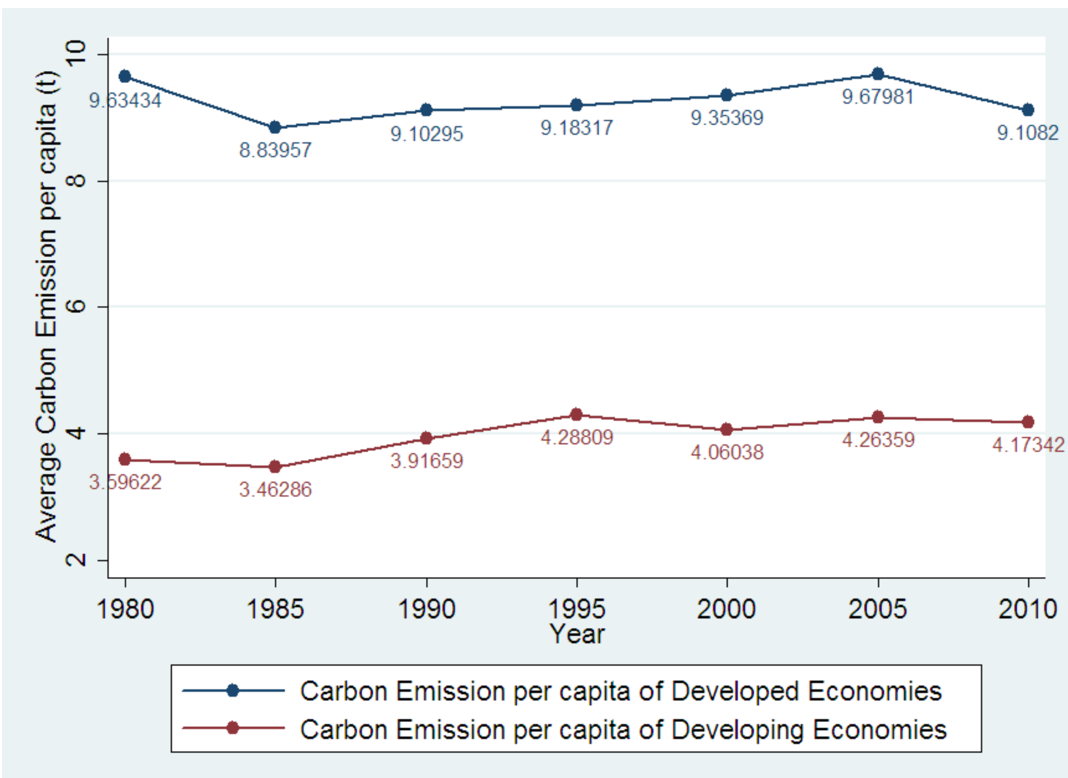


Fig. 5-1. Average carbon emission per capita for developed and developing economies.

Source: World Bank (2016)

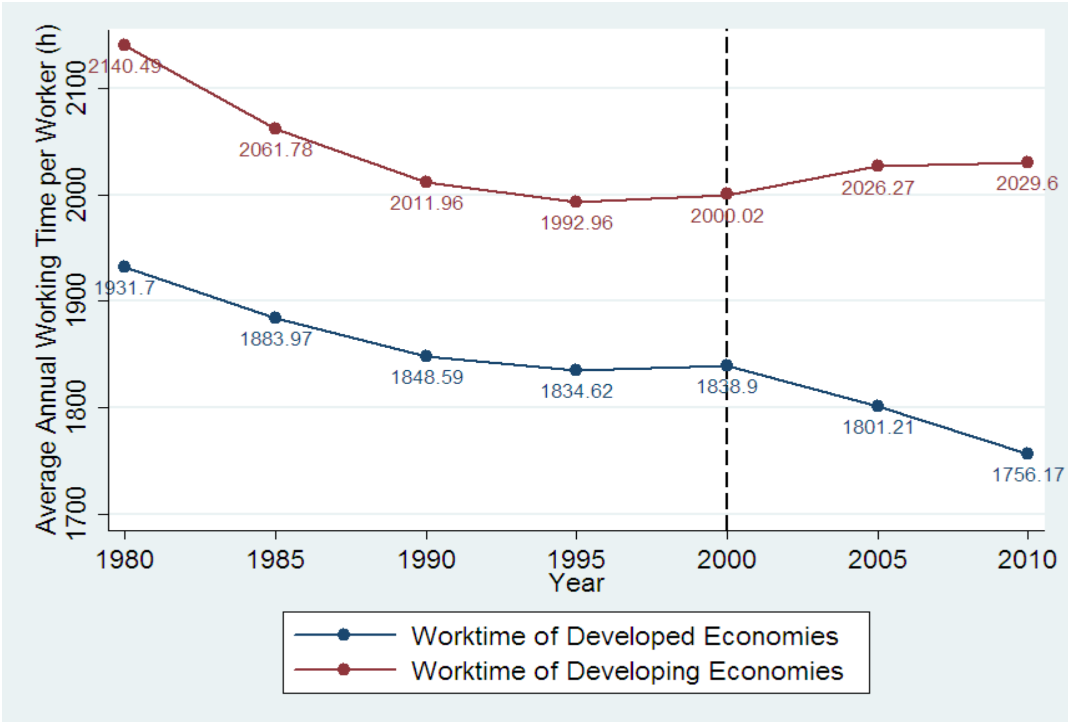


Fig. 5-2. Average annual working time per worker for developed and developing economies.

Source: TCB (2016)

5.4.2 Empirical results

We tested for stationarity of the panel data by applying the panel unit root test (see **Table 5-4**). However, the evidence might not be reliable as the panel unit-root test, which requires cross-sectional independence, experiences strong size distortions and restrictive power when the assumption of independence fails to hold (Bakas & Papapetrou 2014). Therefore, the null of the cross-sectional independence was examined by applying the Pesaran (2004) CD test, which employs the correlation coefficients between the time-series for each panel member (Liddle 2015). Results are shown in **Table 5-5.**

Table 5-4. Panel unit root test for developed and developing countries.

	Variables in Levels				**Variables in first differences**			
	Developed countries		**Developing countries**		**Developed countries**		**Developing countries**	
	Statistic	*Prob*	*Statistic*	*Prob*	*Statistic*	*Prob*	*Statistic*	*Prob*
Carbon p. c.	108.9846	0.0051***	65.5965	0.0009***	430.9701	0.0000***	425.1636	0.0000***
Work-time	95.6738	0.0459**	58.4890	0.0103**	365.5019	0.0000***	121.8243	0.0000***
GDP p. c	88.5379	0.1193	42.6565	0.1466	255.4851	0.0000***	142.9088	0.0000***
Labor. Pro	101.7403	0.0179**	46.7631	0.1000*	178.4706	0.0000***	94.2626	0.0000***
Emp. % Popu	107.7719	0.0063***	32.1973	0.6501	220.7387	0.0000***	140.4168	0.0000***
Ser. % GDP	86.0959	0.0684*	32.0888	0.5616	411.8711	0.0000***	166.0084	0.0000***
Export	94.7738	0.0260**	23.4697	0.8630	352.5098	0.0000***	123.9745	0.0000***
Import	135.2304	0.0000***	47.5482	0.0220**	326.2941	0.0000***	168.5556	0.0000***

Table 5-5. Cross-sectional dependence: absolute value mean correlation coefficients and Pesaran (2004) CD test.

	Variables							
	Carbon p. c.	Work-time	GDP p. c	Labor. Pro	Emp. % Popu	Ser. % GDP	Export	Import
Developed countries	0.471 (13.99*)	0.671 (53.57*)	0.879 (119.32*)	0.895 (109.41*)	0.560 (34.08*)	0.793 (95.61*)	0.952 (119.81*)	0.944 (118.78*)
Developing countries	0.540 (6.37*)	0.373 (4.41*)	0.674 (43.29*)	0.608 (19.69*)	0.686 (17.08*)	0.527 (20.01*)	0.846 (41.77*)	0.843 (40.57*)

Notes: Absolute value mean correlation coefficient shown. CD-test statistic is in parentheses. Null hypothesis is cross-sectional independence. Statistical significance indicated by * < 0.001.

Regression results that were obtained by using the sys-GMM method are displayed in **Table 5-6**. We split the panel into country types ('Developed' and 'Developing') and control for income (GDP per capita) to test compositional effect (Knight et al. 2013). Legitimacy of sys-GMM models requires testing by AR(1) and AR(2), that is an autoregressive process of order one and a second-order autoregressive process (Baltagi 2005). They indicated the statistics of serial uncorrelated residuals of the first and second order in the testing of the panel model. Specifically, AR(1) denotes first order serial correlated residues when $P < 0.05$ due to the differencing, and AR(2) denotes serial uncorrelated residues of second order when $P > 0.05$. Results displayed in the eight models confirmed the expected assumptions. The Sargan test P-values indicated that the null hypothesis (H0: over-identifying restrictions are valid) could not be rejected, and thus instrumental variables used in the GMM estimations were appropriate.

Building upon prior research, we aimed at deepening the analysis to detect correlations of work hours and environmental impacts among different time periods of different country groups. The function of interaction terms infers how the effect of one independent variable on the dependent variable depends on the magnitude of another independent variable (Ai & Norton 2003). Considering this, we made period dummy variables ('Period1' and 'Period2') interact with the work-time indicator, to examine the effects by using the sys-GMM approach. It is important to note that interaction terms are centralized in order to avoid multi-collinearity.

As can be seen from **Table 5-6**, Models 1, 3, 5 and 7 estimate the scale effects of work time on carbon emissions per capita. Results show that, for developed countries, interaction terms of the first sub-period are positive and significant at the 1 percent level, which is consistent with previous research (Schor 2005; Nässén et al., 2009; Knight et al., 2013). However, coefficients in the second sub-period are negatively correlated although they are significant at 1 percent level. Further, no evidence of significant relations appeared in developing groups. For other explanatory variables, only 'Ser. % GDP' indicator poses negative and significant relations with respect to dependent variables across all models. In Models 2, 4, 6 and 8 we test for the existence of a compositional effect. Similar results are generated, coefficients of interaction terms turn to negative values in developed countries and no significant relations exist among developing counterparts.

Table 5-6. Empirical results for developed and developing country groups by using sys-GMM method.

Variables	Developed Countries (37)				Developing Countries (18)			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Work-time	-0.0771**	-0.0808**	0.0398	0.0339	0.0174	-0.0267	0.0581	0.0066
	(0.040)	(0.037)	(0.034)	(0.030)	(0.067)	(0.067)	(0.071)	(0.068)
Work-time* Period1	0.1172***	0.1151***			0.0412	0.0343		
	(0.042)	(0.042)			(0.077)	(0.079)		
Work-time* Period2			-0.1170***	-0.1149***			-0.0409	-0.0341
			(0.042)	(0.042)			(0.077)	(0.079)
Control Variables								
Period1	0.0033	0 .0024			-0.0051	-0.0063		
	(0.006)	(0.006)			(0.009)	(0.009)		
Period2			-0.0033	-0.0024			0.0051	0.0064
			(0.006)	(0.006)			(0.009)	(0.009)
GDP per capita		0.0049		0.0049		0.0060		0.0064
		(0.006)		(0.006)		(0.011)		(0.011)
Labor productivity	0.0074		0.0074		0.0351**		0.0355**	
	(0.011)		(0.011)		(0.015)		(0.015)	
Emp. % Population	0.0056		0.0059		0.0361		0.0362	
	(0.023)		(0.023)		(0.029)		(0.029)	
Ser. % GDP	-0.0703**	-0.0696**	-0.0705**	-0.0699**	-0.0854***	-0.0649**	-0.0868***	-0.0668**
	(0.028)	(0.028)	(0.028)	(0.028)	(0.032)	(0.031)	(0.032)	(0.031)
Export	-0.0205	-0.0197	-0.0210	-0.0203	-0.0013	-0.0026	-0.0016	-0.0029
	(0.014)	(0.015)	(0.015)	(0.015)	(0.011)	(0.011)	(0.011)	(0.011)

Import	0.0207 (0.015)	0.0201 (0.015)	0.0213 (0.015)	0.0207 (0.015)	0.0117 (0.012)	0.0142 (0.011)	0.0121 (0.012)	0.0145 (0.011)
Constant	0.2751** (0.133)	0.2678** (0.1151)	0.2780** (0.131)	0.2710** (0.113)	-0.0663 (0.170)	-0.0264 (0.143)	-0.0689 (0.167)	-0.0294 (0.139)
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.279	0.289	0.301	0.285	0.812	0.755	0.809	0.759
Sargan test P-value	0.681	0.687	0.623	0.631	0.219	0.266	0.204	0.259

Notes: Standard errors in parentheses; *, ** and *** denotes significant p-value at the 10%, 5% and 1% levels, respectively.

5.5 Discussion

Interestingly enough, the results just presented suggest that improved efficiencies generated from the increase of labor productivity may contribute to environmental degradation after 2000 in developed economies, and generally in developing economies. Although the finding goes against our initial presumption, it is in line with prior studies warning about the existence of a re-bound effects in carbon reduction (Lajeunesse, 2009; Druckman et al., 2012). Remarkably, the consistently negative coefficient of the 'Ser. % GDP' across different models indicates that the environment tends to benefit from the growing share of the service industry, which is less carbon-intensive.

The unexpected empirical results implied that the relationship between hours of work and environmental pressures gets de-linked in the case of high-income economies during the last ten years of assessment. This could be observed in **Figs. 5-1** and **5-2**, which show annual working hours per worker in developed economies declined remarkably, whereas carbon emissions per capita remain stable and almost unchanged across the research period. A possible explanation might be that increased non-work hours augmented the environmental impacts, as more leisure time tended to encourage more energy-intensive activities in some cases (Druckman et al., 2012; Nørgård 2013).

This result indicated a re-bound of environmental burdens due to the increasing leisure hours (Nässén et al. 2009). This might be seen as surprising given the conventional view on this issue, which was always based on the assumption that working hours are more energy-demanding than non-working hours. In principle, WTR policies aimed at contributing to energy saving and environmental protection based on the idea of re-structuring personal daily routines towards less energy- consuming activities. However, this was not always the case as leisure hours might be more energy-intensive than working hours. As Druckman et al. (2012) argued, a simple transfer of time from paid work to the leisure period might be employed in more carbon-intensive way. Nørgård (2013, p.67) also pointed out that "more leisure time does not guarantee a lower environmental impact", and "the extra leisure time will tend to require more energy, but the amount will depend on how leisure is spent".

In this line of thinking, reduced work hours might prove to be counter-effective and in turn imposed heavier burdens on the environment, under the conditions that leisure activities (such as car travelling and vacation abroad) were more energy-demanding. Panel regressions suggested that this situation was more likely to occur in high income countries, and Pullinger (2014) also argued that the size of the effects of work-time policies on impacts will substantially depend on the income. Accordingly, increasing leisure hours in countries with higher average incomes tended to provide their inhabitants with increased opportunities to organize multiple and costly energy-intensive activities.

Therefore, environmental impacts induced by less work-time required a careful examination. On the one hand, a narrative of people spending their increasing leisure hours in low intensive ways such as staying with their friends and families, undertaking sports or just resting at home can be imagined. Clearly, this is the vision favored by the perspective of the critics of economic growth (Kallis et al. 2013), who at the same time warned about the certain conditions for this to happen, such as social infrastructure in support of unpaid work and leisure (Gorz 1982). On the other hand, one can also envisage expensive travel and recreational activities during the free time, frequently at the expanse of a high environmental impact (Pullinger 2014). Our results confirmed this call for understanding these two possible ways for mitigating CO_2 emission and other environmental impacts through work policies.

Overall, it appeared that income plays an important role in reducing work-time until a certain point beyond which the impact of work hours on the environment gradually weakens. An underlying reason was that workers with lower wages in developing economies prefer to earn overtime pay, or to find a part-time job with which to support their families. Effects of environmental pressure alleviations induced by WTR in developing economies may be also weakened due to the blurred boundary between working hours and non-working hours. This might explain that work-time in developing economies is less significantly correlated with environmental impacts than in their 'developed' counterpart.

In fact, our finding was not so surprising, since previous empirical works either sample developed countries such as OECD countries (Nässén et al., 2009; Knight et al., 2013), or aggregated developing and developed countries as a whole (Rosnick and Weisbrot, 2006; Hayden and Shandra, 2009). As indicated above, empirical research on the relations between working time and environmental pressure distinguishing between developing and developed economies was scarce. Our finding came to fill in this gap and shed new light on the effects of working time on environmental impacts in developing countries, using the best available data.

5.6 Conclusions

In this article we investigated the effect of working hours on environmental impacts under a dynamic panel approach. Different from previous studies, our panel regression analysis of 55 economies for period 1980 to 2010 demonstrated that work-time is closely (and positively) associated with environmental pressures only before year 2000 for high-income economies. Additionally, developing countries show no evidence of significant correlation. This result complements the conventional views on working time and environmental pressure.

Moreover, this research may frustrate the environmental motivation of WTR policies, i.e. less working hours could contribute to reducing environmental impacts while maintaining and improving levels of well-being. As a consequence, working time policy tools used in pursuing environmental sustainability should be carefully analyzed and adjusted accordingly.

Of course work time is not the sole factor triggering impacts on the environment. Multiple reasons could explain emission variations. For instance, stagnating emissions per capita in developing countries with parallel working time reductions could induce by less work needed for production due to a rise in the capital intensity. In addition, deregulatory policies might dismantle legal and safeguards leading to higher environmental impacts despite working-time reductions. These important questions remain as interesting topics for future work.

Our study provided three improvements upon previous seminal works. First, the use of the sys-GMM method allowed us to capture certain cumulative dimensions of the impact of working hours on environmental pollution. This method took into account aspects that were somehow neglected by static techniques, such as environmental degradation caused by WTR policies in the long term, or the effects of population on future environmental pressures.

The second contribution lied in the classification of developing and developed country groups, which aimed at detecting and comparing the nexus among them. Findings show that correlations of developed economies are significant although this is not the case for developing counterparts.

Lastly, two sub-periods were analyzed in order to examine the correlations that are able to provide detailed information of interest. Results illustrated that significant correlations of work time and CO_2 emissions turn from positive in the first sub-period (1980-2000) to negative in the second sub-period (2001-2010), which suggested a re-bound trend of energy use in recent years.

Future studies on this topic can be enriched in three ways. First, increasing capital intensity of production in developing economies can be included in order to examine its impact on the environment. Second, periods can be split up using less arbitrary methods, such as the panel threshold approach. Third, an analysis could be undertaken to test whether and to what extent the increasing leisure hours in high-income countries is related to the recently changed relationship between work hours and environmental degradation. These may offer new insights into WTR research.

6. When Reduced Working Time Harms the Environment: A Panel Threshold Analysis for EU-15, 1970-2010

6.1 Introduction

Mounting scientific evidences suggest that anthropogenic activities have done great devastation to the global environment since the inception of the Industrial Revolution. These human impacts are exacerbated by population boom and economic expansion (Ehrlich, P. R. and Holdren 1971). For instance, CO_2 emissions, a widely used measure of environmental pressure, reached 36.24 Gt in 2014, almost quadrupling the 1960 level (GCA 2016). This growth strategy, at its heart, is a public goods game, where short-term gains in profits are prioritized over long-term public goods, most notably the environment and natural resources. What are the policy instruments to transition from a public goods game to a coevolutionary game (Perc & Szolnoki 2010; Perc et al., 2012)? One option has to do with working time, which we explore in this paper.

The growth-critiquing communities (Speth 2008) and the de-growth group (Latouche 2010; Kallis 2011; Kallis et al., 2012) enthusiastically support working time reduction (WTR) policies, which regained momentum in the wake of the 2007-09 Global Financial Crisis. **Fig. 6-1** shows a generally downward trend of average annual working time per worker over the period of 1970-2010 in EU-15 countries. We can see that Greece surpassed Ireland to become the country with longest work hours in 1996 and that the Netherlands usually has the shortest work hours among the 15 countries. **Fig. 6-2** illustrates that reduced working hours are not always accompanied by decreasing environmental burden; on the contrary, it is not difficult to see the opposite trend, such as Austria during 1983-2004 as well as Greece, Ireland, and Spain during almost the entire research period. Furthermore, we observe nonlinear relationships for each of the EU-15 countries: while there is a generally declining trend for working hours, the values of the environmental indicators fluctuate. Supporters of WTR policies believe that shorter workweek provides an antidote to over-consumption by scaling back both reduction capacity and spending power; they claim that there would be less environmental pressure due to more leisure time spent doing less energy-intensive activities (Gorz, 1994; Latouche, 2010; van den Bergh, 2011).

Existing empirical studies apply a variety of methodologies to cross-national and household micro-level data and identify a significantly positive effect of working hours on environmental pressure (Schor 2005; Rosnick & Weisbrot 2006; Hayden & Shandra 2009; Nässén et al., 2009; Knight et al., 2013; Shao 2015). These studies indicate that shorter working week is an effective policy option to alleviate environmental burdens, which is in line with de-growth views (Ashford & Kallis 2013). Nevertheless, outside EU countries, working hours have been prolonged in many advanced industrial economies, such as Australia, Japan, Canada, and the U.S., but environmental pressure has not always increased as a result (TCB 2016). Some empirical studies even identify a significantly negative correlation with more comprehensive data samples and advanced statistical methodology (e.g., Shao & Rodríguez-labajos 2016). If this finding is substantiated, when annual hours worked per employee in a specific country are below or above certain thresholds, the relationship will switch from a positive one to one that is negative, vertically asymmetric, and nonlinear. To extend on this front, this study examines how the threshold effect (i.e., the degree separating positive and negative relationships) of working hours affect environmental burden.

Building upon extant works that explore the nexus between working hours and environmental pressures, our paper makes two major contributions. First, we employ a threshold model to account for nonlinearity in the data and specify the level at which the positivity of the relationship experiences reversal. Most existing researches focus extensively on linear models. However, the conflicting results on the worktime- environment nexus suggest that it is necessary to introduce nonlinearity into empirical methodology. As well demonstrated in **Fig. 6-2,** which plots the trends in working time, carbon emissions, and energy use for each of the EU-15 countries, the relationship between working hours and environmental pressures is far from linear. To avoid classifying countries arbitrarily, we split our sample endogenously using the panel threshold model developed by Hansen (1999). This technique selects appropriate threshold values and divides the sample into classes accordingly. In our application, we use estimated thresholds to bin EU-15 countries into different working time regimes. We then estimate environmental pressure elasticities for each working time regime for comparison. To our knowledge, this is the first empirical specification of its kind to account for nonlinear environmental processes. Besides working time, we also consider per capita GDP as a threshold variable. According to extant literature, income can play a dominant role in the relationship between hours of work and environmental impact. The logic is this: people living in wealthy countries are more likely to afford high energy-consuming activities in their leisure time, such as long-distance travelling, while people in less developed economies prefer cheaper activities that often require less energy consumption (Nørgård 2013; Nässén & Larsson 2015; Shao & Rodríguez-labajos 2016). In light of this, to make our results more robust, we use per capita GDP as another threshold variable. Second, based on our model results, we identify the countries whose environmental pressures exacerbate when working hours are scaled back. We estimate threshold values first; specify country regimes using these values; and then calculate the elasticities in different regimes. These empirical results will yield critical policy implications and we discuss them in the last section of this paper.

The remainder of this paper is organized as follows. Section 2 reviews relevant empirical studies on the effect of working time on environmental pressure. Section 3 describes the data and methodology. Section 4 presents results and discussions. Section 5 concludes with implications of our research outcomes and directions for future research.

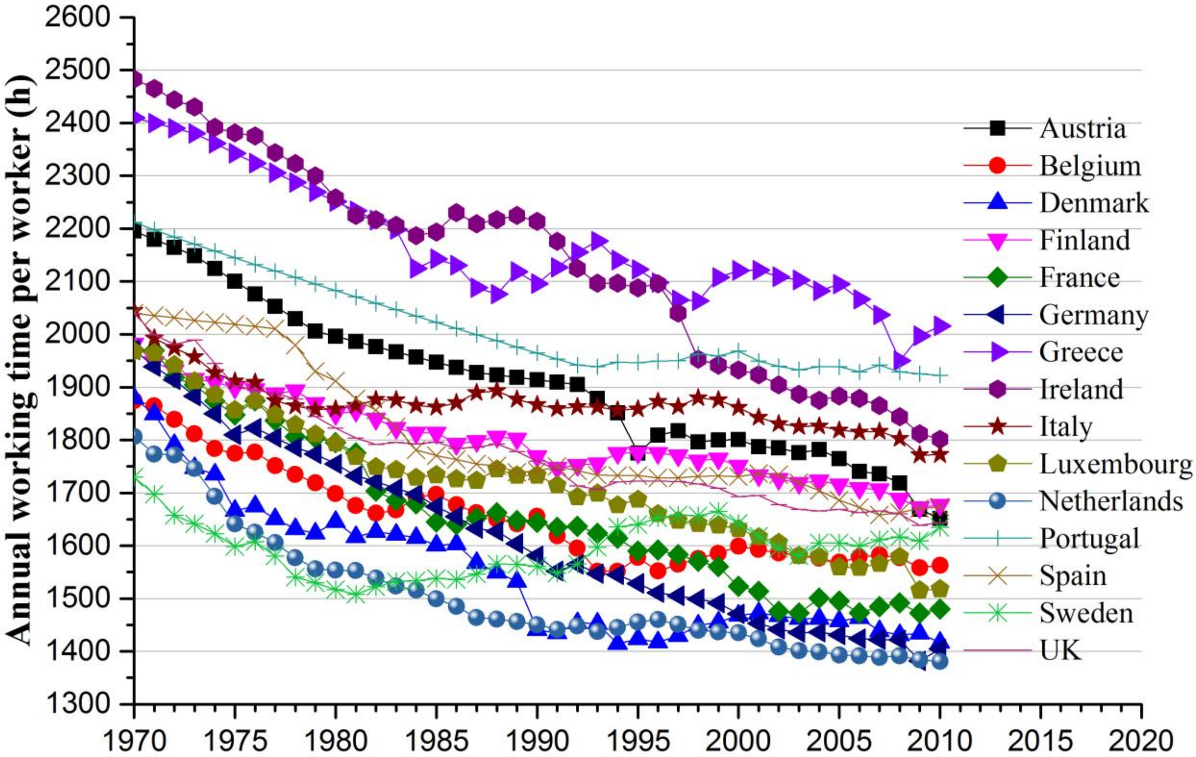
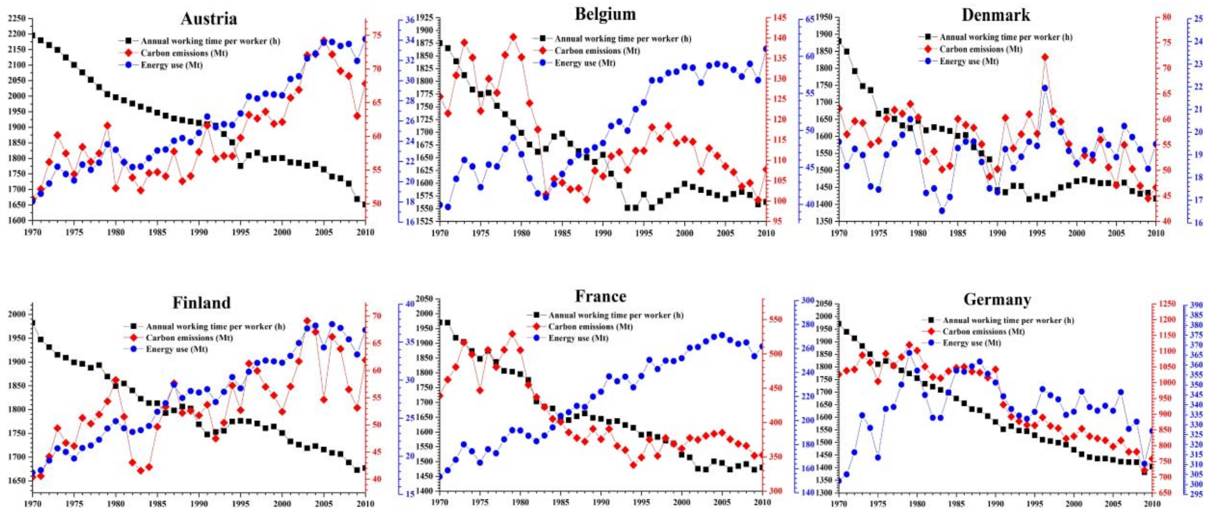


Fig 6-1. Historical changes of the average annual working time per worker for EU-15 during the period 1970-2010 (unit: hours).

Source: TCB (2016)



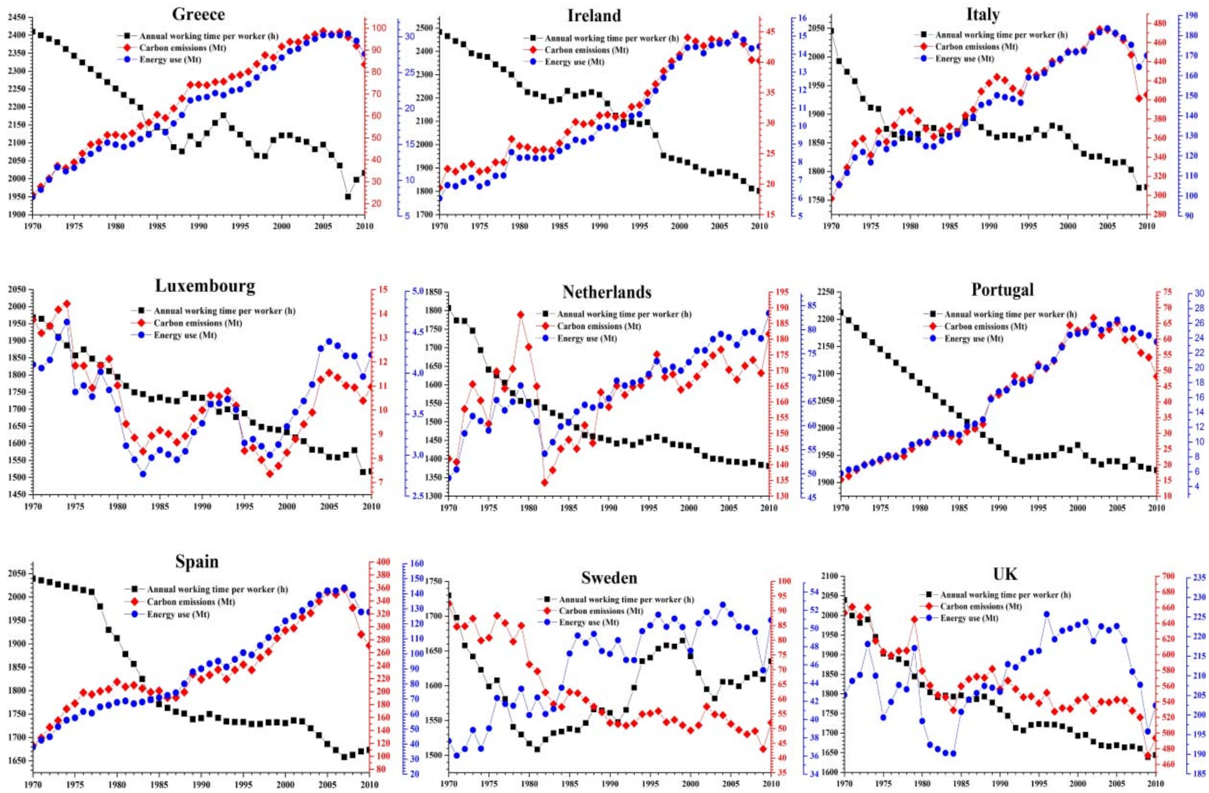


Fig 6-2. The non-linear relations of annual working time per worker, total carbon emissions and primary energy use for EU-15 countries from 1970 to 2010, respectively.

Sources: TCB (2016), World Bank (2016), GCA (2016).

6.2 Literature review

Since the publication of seminal works by Schor (1995) and Hayden (1999) that draw the connection between working time and environmental pressures, several empirical studies followed suit with the then consensus that reduced working time could reduce harm to the environment. Some works focus on a single country. For instance, Spangenberg et al. (2002) demonstrated that reduced working time, coupled with technological innovation, social security system, and green taxes, was needed for Germany to attain economic competitiveness and a high employment rate and to ease the country's environmental pressures between 1994 and 2000. Conducting survey research in France in 2001, Devetter & Rousseau (2011) found that longer working hours only served to encourage goods and energy consumption by fostering conspicuous consumption and unsustainable lifestyles. By analyzing time use in Catalonia from both gender and age perspectives, D'Alisa & Cattaneo

(2013) found that labor shift from the market to the household led to less intensive use of energy and argued that work-sharing at the household level was an essential way to reduce energy use. Nässén et al. (2009) using micro-level household data in Sweden in 2006, found that decreasing work time by 10 percent would induce an average 8 percent reduction in energy use and GHG emissions, while accounting for the income effect and the time effect. Subsequently, Nässén & Larsson (2015) confirmed previous findings that income plays a dominant role in the relationship between environmental impact and hours of work; a 10 percent decrease in working time on average reduced energy use and GHG emissions by 7 percent and 8 percent, respectively. Further, they forecast a gradual reduction towards 30 hours of work per week by 2040 that would halt the growth of energy demands in the long run. Moreover, shorter working week is also strongly upheld by degrowth proponents as an effective way to "kill two birds with one stone" when complemented by a working sharing program, since more people are employed and energy consumption is reduced thanks to shorter working hours (Sekulova et al., 2013; Kallis 2013).

Other scholars have focused on the linear effect of working time on environmental pressures based on cross-national analyses (Dahl & Gonzalez-Rivera 2003). Schor (2005) ran a multiple linear regression to account for ecological footprint in eighteen OECD countries and found significantly positive correlation between working hours and environmental burdens. Rosnick & Weisbrot (2006) simulated environmental impacts of European countries if their economic models were to approximate that of the United States. They found that as working time increases, economic production and consumption increase accordingly, and so does energy consumption. Specifically, they argued that a 1 percent increase in working time leads to a 1.32 percent increase in energy consumption, while holding other factors equal. Hayden & Shandra (2009) also identified a significantly positive relationship between working time and ecological footprint based on a structural equation model covering data from 45 countries across the globe, a finding that still holds after controlling for employment rate, labor productivity, and other relevant variables. Later, in the spirit of economic de-growth theory for developed countries on working time, Knight et al. (2013) examined the effects of working hours on three typical environmental indicators: ecological footprint, carbon footprint, and carbon dioxide emissions. They used a first-difference panel regression on data from 29 high-income OECD countries and discovered that working time has a significantly positive relationship with environmental pressures based on multiple model specifications, except when using carbon dioxide emissions as the dependent variable and GDP per capita as a control variable. Hence, they concluded that WTR policies may contribute to environmental sustainability. In a similar vein, Fitzgerald et al. (2015) confirmed the increasing effects of working hours on energy consumption both in developed and developing countries. **Table 6-1** illustrates the elasticities of environmental burdens with respect to changes in working time. It is not hard to tell that the impact of working hours on environmental pressures varies under different methodological specifications as well as the size and composition of data samples.

Different from aforementioned studies, Shao & Rodríguez-labajos (2016) re-examined the effects by setting carbon emissions per capita as the dependent variable and applying advanced dynamic panel data approach (i.e., system Generalized Method of Moments, sys-GMM) to a comprehensive data from 55 countries worldwide over the period 1980-2010. Challenging the conventional view, their results suggest that the relationship between working time and environmental impact is insignificant in developing economies and that environmental burden may rebound for developed countries, as the correlations between the two indicators turned from being positive during 1980-2000 to being negative during 2001-2010. Shao & Rodríguez-labajos (2016) explained that "more leisure time does not guarantee a lower environmental impact," echoing Nørgård (2013), which suggested that "the extra leisure time will tend to require more energy, but the amount will depend on how leisure is spent" (p.67). Specifically, a simple reallocation of time from paid work to leisure might result in heavier environmental pressure, since having more leisure time tends to encourage more energy-intensive activities in certain cases, such as long-distance car traveling and vacation abroad (Druckman et al. 2012). More often than not, this situation applies to high-income countries, as the magnitude of the effect of work-time policies on the environment hinges upon income level (Pullinger 2014). For instance, people from developing economies tend to spend their extra leisure hours doing things that do not require much energy consumption, such as staying with their families, doing sports, or just resting at home; by contrast, rich communities prefer expensive travel and recreational activities, which usually bring about higher environmental impacts. Following this line of research and building upon prior studies, we want to explore: if the "rebound effect" exists, at which level of working time does carbon emission cease to be reduced further and begin to increase instead? This is especially critical and it comes with important policy implications. By undertaking these estimations, we can distinguish countries that already show negative environmental impact under WTR policies from those who still have the potential to alleviate their environmental burdens by promoting shorter working weeks.

While the aforementioned empirical studies bear their merits, two outstanding issues beg further examination. The first issue concerns the use of ecological footprint as the dependent variable. Ecological footprint converts the flows of energy and matter originating from an activity into corresponding land area that is required to support such flow. Many authors have voiced concern over the appropriateness and effectiveness of ecological footprint as an indicator of environmental pressure. Conceptually, carbon footprint – without a clear and uniform definition – is often used to reflect greenhouse gas emissions (Wiedmann et al. 2006). Methodologically, van den Bergh & Grazi (2014) documented eight major shortcomings, from misspecification of hypothetical land area to misinterpretation of ecological deficit as support for anti-trade sentiments, rendering ecological footprint futile for offering useful information for public policy. Fiala (2008, p.519) calls ecological footprints "bad economics and bad environmental science".

The second issue concerns sample selection; namely, some existing studies incorporate several industrialized countries into their samples without accounting for the fact that these countries demonstrate diverging trends in working hours. While most countries in Europe (e.g., France, Germany, Denmark) have shown a decline in working time, several non-European countries (e.g., Australia, Canada, the United States) have not (Schor 2005; TCB 2016). As Temple (2000) rightfully warns, "one should probably be careful about extrapolating findings from one set of countries to another." Based on these two considerations, we rule out ecological footprint as a valid indicator of environmental pressure in our analysis. Furthermore, we draw our data from EU-15 countries, who share relatively similar socioeconomic trends.

Table 6-1. Studies estimating elasticities of environmental burdens with respect to changes in working time.

Study	Environmental indicators	Elasticity	Method and data structure
Rosnick & Weisbrot (2006)	Energy consumed per capita	1.33	Multivariate regression analysis; 48 countries; 2003-2005
Nässén et al. (2009)	Energy use	0.83	Micro-data analysis, linear regression; Sweden, 2006
	GHG emissions	0.85	
Knight et al. (2013)	Ecological footprint	1.37	First difference panel regression; 29 OECD countries; 1970-2007
	Carbon footprint	1.30	
	Carbon emissions	0.50	
Rosnick (2013)	GHG emissions	0.50	Illustrative scenarios, MAGICC; world-wide economies;1990-2100
Nässén & Larsson (2015)	Energy use	0.70	Micro-data analysis, scenario analysis; Sweden, 2006
	GHG emissions	0.80	
Fitzgerald et al. (2015)	Energy consumption	0.32	Praise-Winsten regression model; 52 countries; 1990-2008

6.3 Data and Methods

This study examines the nonlinear relationship between annual working time per worker and environmental pressure in EU-15 countries. The assumption here is that both working time and per capita GDP have one or more threshold values, giving rise to asymmetric upper and lower boundaries in a nonlinear manner. In this section, we briefly introduce the definitions and sources of data as well as methods used for regression analysis.

6.3.1 Data

6.3.1.1 Dependent variables

Due to controversies surrounding the effectiveness of ecological footprint, as detailed in the previous section (van den Bergh & Grazi 2014; Wackernagel 2014), we use two other commonly used and widely recognized measures – carbon emission and primary energy consumption – as dependent variables (e.g., Rosnick & Weisbrot 2006; Knight et al., 2013). Carbon emissions mainly originate from the burning of fossil fuels, manufacturing of cement, and other processes that involve the consumption of solid, liquid, and gas fuels as well as gas flaring. We use the CO_2 emissions (in thousand metric tons) dataset from the World Bank, (2016). For Germany, such data is unavailable in the World Bank data depository before the German reunification in 1990; we thus supplement it by using 1980-1989 data from the Energy Information Administration (EIA 2016). The second dependent variable, energy consumption, refers to the use of primary energy before transformation to other end-use fuels. It is calculated by adding indigenous production, imports, and stock changes and then subtracting exports and fuels supplied to ships and aircraft engaged in international transport. Primary energy consumption data, measured in thousand metric tons of oil equivalent, comes from the World Bank (2016).

6.3.1.2 Independent variables

Following Hayden & Shandra (2009), we disaggregate GDP per capita into three components to test their effects on the dependent variables: annual working time per worker, labor productivity, and percentage of population employed (i.e., Knight et al., 2013, p.697; Shao & Rodr ǵuez-labajos, 2016, p.230). To be specific, annual working time per worker refers to the total number of hours worked as a worker or as a self-employed person in a given year. Labor productivity is measured as GDP in USD per hour of work in 2013, adjusted for purchasing power parity (PPP). Percentage of population employed refers to the percentage of workers in a given population. All data of the three variables are from The Conference Board Total Economy Database (TCB 2016). TCB, developed by the Groningen Growth and Development Centre (GGDC) in the early 1990s, is a comprehensive database that includes important indicators, such as annual GDP, population, employment, labor productivity, and so on, covering as many as 123 countries worldwide. Particularly, its country-year data of annual working hours per employee are used widely in related works (Knight et al. 2013; Shao 2015).

In addition, GDP per capita, measured in constant 2005 USD, is the sum of gross value added by all resident producers in the economy, plus any product taxes, and minus any subsidies not included in the value of the products. Percentage GDP that comes from trade is the percentage of GDP that is contributed by the sum of exports and imports of goods and services. Percentage of GDP that comes from capital is the percentage GDP of gross capital formation, which consists of outlays, fixed assets of the economy, and the net changes in the level of inventories. Population and urban-population ratio are also included in our analysis. All data described in this paragraph come from the World Bank (2016).

We collected data for a time span of 41 years, from 1970 to 2010, and for all EU-15 countries, from the poorest (Greece) to the richest (Luxembourg) in terms of income. Before running regressions, we decrease the variability of our data and make them distribute normally by taking the log of all these variable values. **Table 6-2** exhibits descriptive statistics and **Table 6-3** shows correlation matrix of all the variables in this analysis. It is not difficult to tell that most variables are correlated with other variables, significant at the 1% level. For instance, we can see that working hour is negatively correlated with carbon emissions and energy consumption, implying that less working time may aggravate environmental burdens, which is in line with aforementioned Druckman et al. (2012), Nørgård (2013), and Shao & Rodríguez-labajos (2016) in Section 2. Further, we find working time is also negatively related to GDP per capita, which corresponds to the arguments of Kallis et al. (2013) that advanced, wealthy countries tend to have shorter working weeks.

Table 6-2. Descriptive Statistics for all variables in this study.

Variables	Mean	Sta. De.	Min	P25	P50	P75	Max
Carbon	11.5496	1.1976	8.9033	10.8382	11.2795	12.7755	13.8700
Energy	10.6817	1.2560	7.9266	9.8658	10.6627	11.7889	12.8105
Hours	7.4804	0.1277	7.2307	7.3881	7.4790	7.5659	7.8172
Labor productivity	3.5574	0.3938	2.3794	3.2846	3.6059	3.8517	4.4124
Emp. % population	-0.8413	0.1369	-1.2039	-0.9483	-0.8471	-0.7413	-0.3258
Trade. % GDP	4.2495	0.4988	3.2510	3.8937	4.1325	4.5970	5.8097
GDP per capita	10.1405	0.4106	8.8868	9.8648	10.1545	10.4073	11.3819

Cap. % GDP	3.1013	0.1705	2.4719	2.9903	3.0963	3.2136	3.7600
population	16.3261	1.3523	12.7343	15.4943	16.1201	17.8149	18.2287
Urban. %population	4.2708	0.1782	3.6585	4.1804	4.2973	4.4033	4.5794

Note: All variables are logarithmized; Sta. De is standard deviation; P25, P50 and P75 denote 25% percentile, median and 75% percentile, respectively.

Table 6-3. The correlation matrix of all variables in this study.

Variables		1	2	3	4	5	6	7	8	9	10
Carbon	1	1.00									
Energy	2	0.98*	1.00								
Hours	3	-0.29*	-0.37*	1.00							
Labor productivity	4	0.15*	0.20*	-0.79*	1.00						
Emp. % population	5	-0.20*	-0.11*	-0.53*	0.41*	1.00					
Trade. % GDP	6	-0.54*	-0.53*	-0.30*	0.54*	0.34*	1.00				
GDP per capita	7	0.05	0.12*	-0.74*	0.93*	0.63*	0.55*	1.00			
Cap. % GDP	8	-0.18*	-0.21*	0.47*	-0.53*	-0.10*	-0.25*	-0.49*	1.00		
population	9	0.94*	0.93*	-0.12*	-0.07	-0.29*	-0.71*	-0.29*	-0.05	1.00	
Urban. %population	10	0.19*	0.27*	-0.71*	0.68*	0.32*	0.28*	0.65*	-0.42*	-0.02	1.00

Note: All variables are logarithmized. Correlation is significant at the 0.01 level (2-tailed).

6.3.2 Method

In order to analyze the influence of working time on environmental pressures, we propose a threshold panel approach, which is quite popular in financial and macroeconomics fields, to bin our sample of EU-15 countries into different regimes. Previous studies have followed a systematic, but somewhat arbitrary, classification of countries. For instance, Fitzgerald et al. (2015) divided 52 countries in their sample into developed and developing countries based just on income level. To improve on this front, we use the panel threshold technique, where a grid search performs the selection of appropriate threshold values. This technique employs threshold variables to generate several regimes endogenously so as to avoid potential errors originating from arbitrary determination of segmentation points (Hansen 1999). It can produce one or multiple threshold level(s) to bin the data into two or more regimes depending on whether the threshold variable is above or below certain threshold values (Ben Cheikh &

Louhichi 2016). In our study, this technique allows us to split the sample into different classes based on the value of annual working hours per worker and per capita GDP.

First proposed by Tong (1978) as a viable econometric method, this technique has been developed into the widely used Threshold Auto-Regression (TAR) for nonlinear time-series data in economic and financial realms. Some studies have also used TAR to analyze cross-sectional panel data (see Tiao & Tsay 1994; Potter 1995; Martens et al., 1998). In TAR, the existence of threshold effects must be verified before estimates can be calculated. However, the presence of a nuisance parameter will result in a non-standard distribution of test statistics (the "Davies Problem", see Davies 1987; Andrews & Ploberger 1994). To tackle this issue, Hansen (1999) proposed a bootstrap method to generate test statistics with an asymptotic distribution. In this case, if the null hypothesis (H_0) is rejected and threshold effects do exist, there is super-consistency in the least squares estimators of thresholds and the asymptotic distribution of OLS estimators can be further deduced (Chan 1993). However, non-standard distribution coexists with nuisance parameters. To solve this problem, Hansen (1999) explored the asymptotic distribution of statistics through a simulation of "likelihood ratio" (LR) test.

To estimate nonlinear threshold effects, a two-stage ordinary least squares (OLS) approach is proposed by Hansen (1999). In the first stage, threshold value γ, which is the corresponding sum of squared errors (SSR), is calculated via OLS; then threshold value $\hat{\gamma}$ is obtained using the minimum SSR based on presumed threshold values. In the second stage, coefficients are estimated for different segments that are separated by the threshold values.

6.3.2.1 Threshold model

A threshold model may contain multiple thresholds. In our case, we present a one-threshold model, which can serve as the basis for developing more complicated ones. According to Hansen (1999), the equation with one potential threshold for balanced panel data { y_{it} , q_{it} , x_{it} ; $1 \le i \le N$ } is:

$$y_{it} = \mu_i + \beta_1 x_{it} I(q_{it} \le \gamma) + \beta_2 x_{it} I(q_{it} > \gamma) + e_{it} \quad (1)$$

where y_{it} denotes environmental pressure for country i in year t; μ_i represents country-specific effect; e_{it} is an independently and identically distributed ($i.i.d.$) random disturbance with mean of zero and variance of σ^2 (i.e., $e_{it} \sim i.i.d.(0, \sigma^2)$); x_{it} refers to various exogenous shocks; $I(.)$ is an indicator function that takes on the value of 0 or 1; q_{it} is the threshold variable; and γ is the assumed threshold value. The unknown coefficients, β_1 and β_2, represent the impact of the variable x_{it} on the dependent variable y_{it} for $q_{it} \le \gamma$ and $q_{it} > \gamma$, respectively. Eq. (1) can be expressed as follows:

$$y_{it} = \begin{cases} \mu_i + \beta_1 x_{it} + e_{it}, & q_{it} \le \gamma \\ \mu_i + \beta_2 x_{it} + e_{it}, & q_{it} > \gamma \end{cases} \quad (2)$$

Further, if $x_{it}(\gamma) = \begin{pmatrix} x_{it} I(q_{it} \le \gamma) \\ x_{it} I(q_{it} > \gamma) \end{pmatrix}$ and $\beta = (\beta_1, \beta_2)`$, then Eq. (2) can be re-written subsequently in a more compact form that is convenient for analysis:

$$y_{it} = \mu_i + \beta x_{it}(\gamma) + e_{it} \quad (3)$$

The purpose of this study is to estimate unknown parameters γ and β, given x_{it} and y_{it} from sampled countries in a given time period.

6.3.2.2 Estimation of threshold model

Since Eq. (1) can be estimated within group, we can eliminate individual fixed effects μ_i by first calculating the average environmental pressure of each individual country:

$$\bar{y}_i = \mu_i + \beta\bar{x}_i(\gamma) + \bar{e}_i \tag{4}$$

where $\bar{y}_i = T^{-1}\sum_{t=1}^{T} y_{it}$, $\bar{e}_i = T^{-1}\sum_{t=1}^{T} e_{it}$

$$\bar{x}_i(\gamma) = T^{-1}\sum_{t=1}^{T} x_{it}(\gamma) = \begin{pmatrix} T^{-1}\sum_{t=1}^{T} x_{it} I(q_{it} \le \gamma) \\ T^{-1}\sum_{t=1}^{T} x_{it} I(q_{it} > \gamma) \end{pmatrix}$$

We subtract Eq. (3) from Eq. (4) to obtain the following equation:

$$y^*_{it} = \beta x^*_{it}(\gamma) + e^*_{it} \tag{5}$$

where $y^*_{it} = y_{it} - \bar{y}_i$, $x^*_{it}(\gamma) = x_{it}(\gamma) - \bar{x}_i(\gamma)$, $e^*_{it} = e_{it} - \bar{e}_i$

Then, using Y^*, $X^*(\gamma)$ and e^* to represent the data stacked over all individuals, Eq. (5) is equivalent to:

$$Y^* = X^*(\gamma)\beta + e^* \tag{6}$$

Therefore, for any given threshold value γ , coefficient β can be calculated via OLS:

$$\hat{\beta}(\gamma) = (X^*(\gamma)` X^*(\gamma))^{-1} X^*(\gamma)` Y^*$$

Now that $\hat{\beta}(\gamma)$ is obtained, we can easily estimate the value of residual:

$$\hat{e}^*(\gamma) = Y^* - X^*(\gamma)\hat{\beta}(\gamma)$$

And then we calculate the sum of squared errors (SSE):

$$\begin{aligned} S_1(\gamma) &= \hat{e}^*(\gamma)`\hat{e}^*(\gamma) \\ &= Y^{*`}(I - X^*(\gamma)`(X^*(\gamma)`X^*(\gamma))^{-1} X^*(\gamma)`)Y^* \end{aligned} \tag{7}$$

Finally, we obtain estimated threshold value using the corresponding γ, according to the principle of minimizing SSE:

$$\hat{\gamma} = \arg\min_{\gamma} S_1(\gamma) \qquad (8)$$

Now we get estimator coefficient $\hat{\beta} = \hat{\beta}(\hat{\gamma})$. The residual-vector estimator is $\hat{e}^* = \hat{e}^*(\hat{\gamma})$. The estimator for residual variance is:

$$\hat{\sigma}^* = \frac{1}{n(T-1)} \hat{e}^{*`} \hat{e}^* = \frac{1}{n(T-1)} S_1(\hat{\gamma}) \qquad (9)$$

6.3.2.3 Threshold effects testing

For single-threshold model (Brana & Prat 2016), we employ Hansen (1999) LR test ($LR_1 = (S_0 - S_1)/\hat{\sigma}_1^2$) to examine the hypothesis:

$$H_0^1 : \beta_1 = \beta_2, \quad H_1^1 : \beta_1 \neq \beta_2$$

Obviously, under the null hypothesis (H_0), no threshold exists and this classic testing no longer provides standard distribution. Given that, we can obtain the empirical distribution of LR test through the bootstrap method, proposed by Hansen (1999) and referenced in Ben Cheikh & Louhichi (2016), to correct the non-standard distribution caused by the presence of the nuisance parameter. Suppose that LR_1 is larger than the empirical critical value, we can infer that significant threshold effects exist (Che 2013). To further confirm threshold numbers, we use $LR_2 = (S_1 - S_2)/\hat{\sigma}_2^2$ and $LR_3 = (S_2 - S_3)/\hat{\sigma}_3^2$ to test the following hypotheses, based on which the number of threshold(s) can be confirmed:

$$H_0^{\ 2} = single - threshold, \quad H_1^2 = double - thresholds$$

$$H_0^3 = double - thresholds, \quad H_1^3 = triple - thresholds$$

6.3.2.4 Confidence interval of threshold estimators

Hansen (1999) points out that confidence interval can be built according to the following equation:

$$LR_0(\gamma) = (S_1(\gamma) - S_1(\hat{\gamma})) / \hat{\sigma}^2 \qquad (10)$$

We use Eq. (10) to test $H_0 : \gamma = \gamma_0$. H_0 is rejected if $LR_0(\gamma_0)$ is large enough. It should be noted that $LR_0(\gamma_0)$ is different from LR_1, since the former tests $H_0 : \gamma = \gamma_0$ while the latter tests $H_0 : \beta_1 = \beta_2$.

Hansen (1999) proved, under certain assumptions, that critical value can be calculated:

$$c(\alpha) = -2\log(1 - \sqrt{1-\alpha}) \qquad (11)$$

According to Eq. (11), $H_0 : \gamma = \gamma_0$ can be rejected if $LR_0(\gamma_0)$ exceeds $c(\alpha)$ and threshold value $\hat{\gamma}$ is within the confidence interval.

6.4 Empirical Analysis

6.4.1 Results and discussions of panel threshold models

As mentioned earlier, we examine the panel threshold effects by considering two threshold variables (i.e., annual working hours per worker and GDP per capita) on two environmental indicators (i.e., carbon emissions and energy consumption) in an effort to fathom the nonlinear relationship between working time and environmental pressures with asymmetric upper and lower boundaries. To achieve this, four models are presented in this study. Critical values of 10%, 5%, and 1%, along with F-test statistics and threshold values for each model, are shown in **Table 6-4**. We find that all models have two thresholds in the regression relationship at the 1% significance level except for the interaction of annual working hours per worker and energy consumption for the double-threshold effect. Therefore, we use two thresholds for our regression analysis. When working time is made the threshold variable, the threshold values are 7.592 and 7.727 for carbon emissions and 7.303 and 7.600 for energy consumption. When GDP per capita is set as the threshold variable, the threshold point estimates are 9.633 and 10.397 for carbon emissions and 9.633 and 10.601 for energy consumption.

Table 6-4. Testing for the threshold effects of working time and GDP per capita on environmental indicators.

Environmental indicators	**Threshold variables**	**Threshold effects**	**F-statistics**	**Critical values**			**Threshold values**	**95% confidence interval**
				10%	5%	1%		
Carbon emission	*Annual working hours per worker*	Single threshold	130.105***	36.236	53.698	99.934	7.592	(7.586 ,7.599)
		Double threshold	117.711***	36.845	49.980	88.907	7.727	(7.710 ,7.727)
		Triple threshold	15.702	12.632	17.299	33.223		
	GDP Per capita	Single threshold	230.786***	57.772	82.088	133.613	9.633	(9.600 ,9.633)
		Double threshold	68.550***	21.070	31.886	52.412	10.397	(10.394 ,10.411)
		Triple threshold	36.367	36.751	48.474	67.607		
Energy consumption	*Annual working hours per worker*	Single threshold	97.080***	35.065	47.634	86.131	7.600	(7.586 ,7.606)
		Double threshold	25.194**	21.027	28.923	55.212	7.303	(7.303,7.328)
		Triple threshold	12.804	19.161	27.425	45.698		
	GDP Per capita	Single threshold	213.656***	66.551	88.267	177.031	9.633	(9.628 ,9.641)
		Double threshold	118.860***	26.534	38.251	68.678	10.601	(10.584 ,10.603)
		Triple threshold	66.478	17.048	23.939	43.938		

Notes：(1) Six-hundred bootstrap replications are employed for each of the three bootstrap tests;

(2) ***, ** and * denote that variables are statistically significant at 1%, 5% and 10% respectively. Same apply to the following tables.

The coefficients and t-values are reported in **Table 6-5**. We first examine the effect of control variables on the outcomes. Labor productivity has a positive effect, significant at the 1% level, in both Models 1 and 2. This reaffirms the "Jevons Paradox," where production efficiency would aggrandize rather than mitigate environmental pressures as a result of price reduction and excessive consumption (Yu et al., 2013; Chitnis et al., 2014; Bourrelle 2014; Ghosh & Blackhurst 2014). Coefficients of employment-to-population ratio show significantly positive effects on dependent variables, indicating more negative environmental effects caused by workers than non-workers. This finding is consistent with Knight et al. (2013), who argued that employment-to-population ratios in OECD countries have a positive effect on total ecological footprint, carbon footprint, and carbon emissions, significant at the 1% level. Percentage of trade to GDP is significant only in the model predicting energy consumption, reflecting the important role of energy trade in Europe. Percentage of gross capital formation to GDP is insignificant across all estimations, it has a positive effect on carbon emissions and a negative one on energy consumption. Effects of GDP per capita are significantly negative, suggesting that wealthy countries among EU-15 possess more advanced environmental technologies and more effective regulations to tackle environmental problems. Population has an overall significantly negative effect on carbon emissions. During the time period of interest, most EU-15 countries experienced a gradual population growth; however, carbon emissions had declined partly thanks to the introduction of emissions reduction schemes. Lastly, we find the percentage of urban population to be positively related to both environmental indicators at 1% significance level, revealing that environmental pressures increased alongside urbanization.

We now discuss results from Model 1, where carbon emissions are the outcome variable. The two thresholds split annual working time per worker into three asymmetric phases: high-level working time (above 7.727), mid-level working time (between 7.592 and 7.727), and low-level working time (below 7.592). As the results show, for high-level working time phase, working hours have a negative effect on carbon emissions; in other words, reducing working time during this stage may lead to an increase of carbon emissions, while holding other factors constant. By contrast, countries in the mid-level working time regime had carbon emissions elasticity of 3.49%: a 1% decrease in working hours caused a 3.49% reduction in carbon emissions, a finding consistent with those in Hayden & Shandra (2009), Knight et al. (2013). Similarly, countries in the low-level phase exhibit a positive relationship between working hours and carbon emissions, significant at the 1% level, but the magnitude (coef = 0.04) is much smaller than that for the mid-level regime. This suggests that as working time shortens, there are diminishing returns to reducing working time in an effort to cut carbon emissions. To piece these together, the sign of the relationship between working time and carbon emissions shifts from negative to positive, as the length of working hours decreases. Reducing working hours has different effects on environmental burdens based on which working time regime a country belongs to.

We then discuss our results from Model 2, where energy consumption is the outcome variable. The two thresholds split annual working time per worker into three regimes: high-level (above 7.600), mid-level (between 7.303 and 7.600), and low-level (below 7.303). We observe a significantly negative relationship between working hours and energy consumption for high working time countries. The relationship turns significantly positive with an estimated coefficient of 2.40 for mid-level working time countries. For low-level working time countries, a significantly negative correlation between working hours and energy consumption, contrary to what we find in Model 1. Here when working hours are reduced beyond a certain point, shortening working hours can increase energy consumption, which echoes Nørgård (2013, p.67), who argued that "more leisure time does not guarantee a lower environmental impact."

Based on the above analysis, environmental burdens can be aggravated via worktime reduction. To explain the discrepancy between the trends in energy consumption and carbon emissions for low-level working time countries, we reckon that one possibility lies in the outcome's sensitivity to shortened working time. One piece of evidence is that the coefficient of annual working time per worker for low-level working time countries (0.04) is much smaller than that for mid-level working time countries (3.49) in Model 1. If working time continues to decline, negative effect can be predicted. To further confirm the negative impact of shorter working time, we now set GDP per capita as the threshold variable.

Table 6-6 presents result of the effect of working time on carbon emissions and energy consumption, where GDP per capita is the threshold variable. Generally speaking, the significance and magnitude of control variables are very similar to those in **Table 6-5**, thus we skip this part and instead focus on explaining the panel threshold effect. For both Models 3 and 4, we observe correlations turning from being significantly negative at high per capita GDP phase into being significantly positive at mid per capita GDP phase. The relationship becomes negative again once working time crosses the lower threshold boundary, which is similar to the pattern in Model 2. One possible explanation is that people in rich countries tend to engage in leisure time activities that are more energy-consuming and carbon-intensive than working. By contrast, people from less well-off countries can only afford activities that do not require as much energy, causing comparatively smaller damages to the environment (Druckman et al. 2012).

Table 6-5. Regression estimate results of working time as threshold variable.

Variables	**Model 1: Carbon emission**			**Model 2: Energy consumption**		
	Coefficients	t-ols	t-white	Coefficient	t-ols	t-white
Labor productivity	2.791	13.49***	4.26***	2.158	12.39***	3.08***
Emp. %population	3.528	14.68***	4.40***	2.145	10.49***	2.86**
Trade. % GDP	-0.0237	-0.50	-0.22	0.141	3.49***	1.72
GDP per capita	-2.743	-13.89***	-4.13***	-1.856	-11.25***	-2.78**
Cap. % GDP	0.0227	0.46	0.24	-0.0495	-1.19	-0.64
Population	-0.936	-4.30***	-1.95*	0.0185	0.11	0.04
Urban. %population	1.924	13.83***	4.66***	1.731	14.08***	4.76***
anu_lt	0.0372	12.10***	5.27***	-0.0153	-4.91***	-2.56***
anu_mt	3.490	14.10***	4.52***	2.396	10.89***	2.80***
anu_ht	-0.05	-10.57***	-6.62***	-0.0227	-8.07***	-2.56***

Notes: (1) anu_lt, anu_mt and anu_ht denote parameters of annual working time per worker in low-, mid- and high-level annual working time phases, respectively.

(2) t-ols denote t-values under homogeneous assumption, t-white denote t-values under heterogeneous assumption, same apply to the following.

Table 6-6. Regression estimate results of GDP per capita as threshold variable

Variables	**Model 3: Carbon emission**			**Model 4: Energy consumption**		
	Coefficient	t-ols	t-white	Coefficient	t-ols	t-white
Labor productivity	0.267	4.15***	1.82*	0.488	10.72***	3.70***
Emp. %population	0.811	6.76***	3.15***	0.443	5.12***	2.05*
Trade. % GDP	0.0467	0.85	0.37	0.100	2.61***	1.10
Cap. % GDP	-0.00651	-0.12	-0.05	0.0168	0.41	0.24
Population	-0.653	-2.82***	-0.90	0.386	2.37**	0.81
Urban. %population	1.518	9.53***	4.30***	1.346	11.69***	3.65***
anu_lg	-0.0418	-11.06***	-3.26***	-0.0318	-12.15***	-3.85***
anu_mg	0.890	4.33***	1.38	1.242	8.60***	4.04***
anu_hg	-3.46	-8.31***	-3.46***	-0.0289	-10.68***	-3.52***

Notes: (1) anu_lg, anu_mg and anu_hg are parameters of annual working time per worker in low-, mid- and high-level GDP per capita phases, respectively;

(2) GDP per capita does not report in this table as control variable due to the application as threshold variable.

6.4.2 Number of countries in three phases for selected years

As previous discussions suggest, we find significant threshold effects in both cases, where working time and GDP per capita are used as threshold variables. Our threshold models indicate that there exist nonlinear relationships between working hours and environmental impacts. Setting working time as the threshold variable, the correlation between working time and carbon emissions shifts from being negative to being positive. However, in the case of energy consumption and in the scenario where GDP per capita is the threshold variable, the sign of correlation between working time and the outcome shifts from being negative to being positive and then back to being negative.

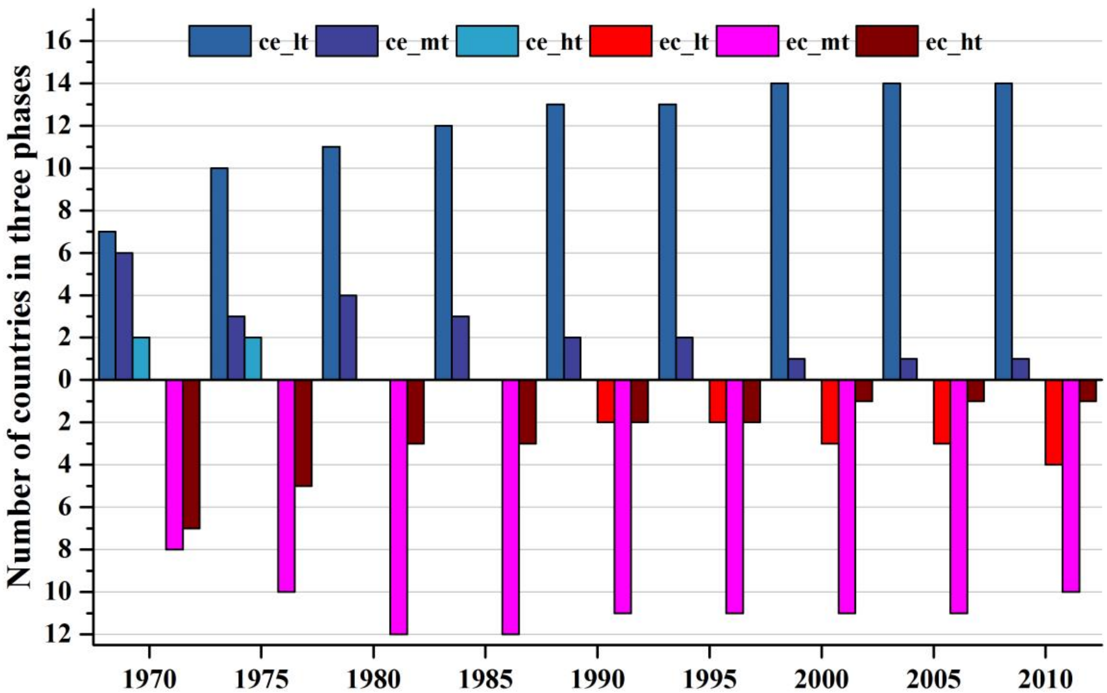


Fig 6-3. Number of countries in three phases of annual working time per worker for selected years.

Notes: (1) ce_lt、ce_mt、ce_ht denote low-, mid- and high- level annual working time phases when we regard carbon emission as environmental indicator;

(2) ec_lt、ec_mt、ec_ht denote low-, mid- and high- level annual working time phases when we regard energy consumption as environmental indicator.

Fig.6-3 reports the number of countries in each of the three phases (i.e., low-, mid-, and high-level annual working hours per worker, segmented by two threshold values using working time as the threshold variable) in 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005, and 2010, respectively. For carbon emissions, the number of countries in high- and mid-level working time phases gradually declined and no country has been at the high-level stage since 1980. Greece remained the only country in the mid-level phase until 2010; in fact, Greece has the longest annual working hours per worker at about 2016 hours, higher than any other European country in our analysis.

As for energy consumption, **Fig. 6-3** illustrates that the number of countries at high-level stage has decreased from seven in 1970 to one in 2010. By comparison, countries in the low-level phase increased from one in 1987 to four in 2010; namely, France, Denmark, Germany, and the Netherlands, whose workforce worked the least with annual working hours at 1480h, 1417h, 1404h, and 1381h, respectively. The significantly negative correlation illustrated in Model 2 implies that higher environmental burden induced by less working hours has already occurred in these four countries.

6.5 Conclusion, implication, and further research directions

Following Druckman et al. (2012), Nørgård (2013), and Shao & Rodríguez-labajos (2016), we further explore the possibility that shorter working week could aggravate environmental pressures under certain conditions. Our paper improves upon past works by specifying such conditions. We bin countries into different working time regimes, separated by thresholds of working time or per capita GDP, to investigate the threshold effect of working hours on environmental pressures measured by carbon emissions and energy consumption, using panel data from EU-15 between 1970 and 2010. After splitting our sample into three regimes with two threshold values, we identify significantly negative correlations between working time and environmental burden at low-level working time phase, with the only exception of using working hours as the threshold variable and carbon emissions as the outcome variable. Therefore, a sheer reduction in working hours will not necessarily translate into less environmental pressure, which reaffirms the arguments of Shao & Rodríguez-labajos (2016, p.233) that “reduced work hours might prove to be counter-effective and in turn impose heavier burdens on the environment.”

In addition, using working hours as the threshold variable, we find Greece to be the only country consistently having long working hours among EU-15; France, Denmark, Germany, and the Netherlands are at low-level working time phase, where shorter workweek led to more environmental pressure. In light of this, we may infer that income plays an essential role in the process (Pullinger 2014). For countries that having more leisure time while commanding higher salaries meant the possibility of engaging in more expensive and energy-demanding activities, such as driving long distances and traveling by air. In comparison, people living in countries with lower incomes are more likely to engage in activities that are less harmful to the environment, such as playing sports, sleeping, watching television, and socializing (Nässén et al., 2009; Nørgård 2013; Shao & Rodríguez-labajos 2016). Therefore, short working week is not necessarily beneficial for the environment and its effect is compounded by various factors such as the income. This result gives rise to the important policy implication that "the less, the better" is too general a statement to hold true for worktime-environment nexus, where the relationship can go in either direction as working time decreases.

If the current trend continues, working hours in EU-15 countries will keep decreasing in the foreseeable future (see **Fig.6-1**). Eventually, all of them will enter the phase where worktime reduction contributes to environmental deterioration. As we already demonstrated in this study, harmful environmental effects may result when working time decreases beyond a certain threshold level. Hence, one problem policy makers have to tackle is how to design working hour length (increase, if necessary) so that environmental damages can be minimized, especially for certain European countries with shorter working weeks.

To this end, more elaborations are needed for policy makers while difficulties are obvious. One obstacle is the rooted belief that there is a close linkage between shorter working time and higher employment rate, but this claim has so far received very little empirical support (Altavilla et al. 2005). Even if we were to believe that working time and employment rate go hand in hand, the observed unemployment rate reduction is still significantly lower than forecasts (Hunt 1998; Logeay & Schreiber 2004). Moreover, further working time reduction comes with high costs. A recent experiment of six-hour working day in a retirement home in Sweden, where nurses' work hours were reduced to merely 30 hours per week, is a case in point. Although the nurses reported higher levels of happiness, the experiment was so costly that it would be unwise to replicate or expand it at the regional or national scale in the foreseeable future (Oltermann 2017; Rogers 2017).

Deep-rooted social and cultural norms that everyone has the right to rest and popular existing pro-rest policies pose more serious obstacles for countries to reverse decreasing working time. To protect the European workforce, EU countries subsequently adopted the Working Time Directive (WTD) under Article 118a of the Treaty of Rome since 1993. The aim of WTD is to "improve the working environment to protect workers' health and safety" (Mommaerts 2009). Toward this end, working hours are legally restricted: maximum permissible weekly working hours of no more than 48 hours; a rest period of no less than 11 consecutive hours per day and 35 consecutive hours per week; minimum four weeks paid annual leave and no more than 8 hours of night work in any 24-hour period (Zbyszewska 2013). However, certain member countries overcorrected the policies and further shortened the workweek in the name of reducing unemployment and improving well-being and negative effects thus generated, such as the high cost for business activities. In this light politicians tried to revise the WTR policies which are "based off" of WTD. Take France as an example, the government attempted to prolong the famous 35-hours workweek via reforming labor regulations to reduce labor costs and improve French companies' international competitiveness. However, as this reform may empower employers to prolong legal working hours and reduce overtime pay, it can potentially jeopardize the welfare of the working people. Accordingly, this proposal instigated fierce nation-wide demonstrations and stagnated (Chazan 2016). It is thus no easy task to pull people from leisure and push them back into work via plain changes to labor regulations, especially when working people are already accustomed to relatively short working weeks and are reliant on free time to release stress, improve personal well-being, and reboot productivity (Wunder & Heineck 2013; Smedley 2014; Mogielnicki 2016; Artazcoz et al., 2016).

Among the policy tools, income tax cut stand by providing possibility for countries whose environment pressures exacerbate as the average working hours decrease to effectively increase working hours to benefit the environment. Historically, Europeans worked slightly more than Americans. Things began to change when the marginal tax rate in Europe rose faster than that in America, leading to shorter work weeks and longer vacations in Europe. The logic is two-fold. On the one side, there is a cultural preference for leisure among Europeans. Europeans were more unionized and were more likely to demand shorter working hours than higher wages (Landsburg 2006). On the other side, higher income tax rates meant that larger portions of labor earnings were being taken away, so the marginal return to labor was lower, disincentivizing European workers to labor longer. If European governments are able to provide income tax cuts, workers are able to claim a larger share of their hourly work payoffs, incentivizing them to work longer and contributing ultimately to lessening environmental pressures.

This study lays the groundwork for future studies to further explore in at least four directions. First and foremost, researchers can take into account different socioeconomic, cultural, and historical contexts that may influence what is deemed as the optimum working hours. Second, future researchers can perform similar analyses for different geographic regions of the world instead of focusing just on EU countries. Moreover, researchers can use environmental indicators other than carbon emissions and energy consumption, such as ecological footprint. They can also employ another interesting working time indicator, such as annual working hours per capita rather than per worker. Third, future researchers may opt for dynamic threshold models to better control for temporal changes and test whether robust hold in this new framework, an example of which can be found in Vinayagathasan (2013). Lastly, future researchers may employ new threshold values or simultaneously use multiple threshold variables in their models (see Kuo et al., 2013) to explore effects on environmental pressure.

7. Conclusions

The five empirical analyses aim to improve our understanding of the effect of working time reduction (a potentially voluntary instrument) and economic recession (an involuntary process) on the environment (i.e., carbon emissions and domestic material consumption in our studies), in order to provide new insights on the different scenarios of combatting global climate change and environmental degradation; this corresponds to the necessity of making quantitative analysis, as established in part 1.1.4.2. A special effort was made to identify whether shorter working hours increase environmental pressure, what factors play an important role in this process, and which countries already demonstrate a harmful impact on the environment due to WTR policies. In addition, using various quantitative methods, this thesis roughly calculates how many carbon emissions were saved due to recessions, and illustrates the essential role of GDP decline in carbon mitigation compared to other potential drivers such as renewable energy, oil price and environmental-friendly technologies. Furthermore, the results reveal that periods of recession are significantly negatively correlated with material use, i.e., recessions tend to coincide with dematerialization. Material use decreases in recession years, but the significant correlation between growth and material use becomes weaker as growth rates increase. In this final chapter, I briefly summarize the main findings of the study and explore its implications for future research and policy.

7.1 Summary of main findings

In *Chapter 2*, I try to build a solid quantitative basis for assessing the effects of recessions on carbon emissions. To this end, I investigate the impacts of recessions on CO_2 emissions from the combustion of fossil fuels and cements for 153 main economies around the world from 1960 to 2014. First, I examine the basic character of world recessions, and I find that nearly half of them are associated with an absolute reduction in CO_2 emissions. In this light, to roughly calculate the carbon emissions saved due to recession, two counterfactual models of emissions are constructed around the five major global economic events: on the one hand, on a country-by-country, recession-by-recession basis and, on the other, on a global basis. Results reveal that nearly one year's worth of carbon emissions at their 2014 level has been avoided since 1960, which amounts to about 1.5 world emission equivalents. Among the five events, the 1979 US savings and loans crisis is the one that has saved most carbon emissions. Furthermore, econometric estimations confirm that recession is the most determinant factor in carbon mitigation. To have the equivalent effect of a recession on CO_2 emissions, oil price has to rise six-fold and renewable energy capacity has to grow 12.4 times for Annex II countries. Final testing demonstrates no evidence of a recession backfire; a positive long-term effect can be expected.

Chapter 3 examines the relationship between material use and economic fluctuation. Although numerous studies on material flow analysis and impact analysis of recession on economic/ financial variables exist, I am the first to try to connect these two research domains by using econometric tools to empirically examine the variation of domestic material consumption along with changing economic growth rate in a sample of 150 economies between 1970 and 2010. Several important conclusions can be drawn: First, global domestic material consumption has generally been growing in concert with global GDP; the only phase of global dematerialization occurred between 1990 and 1992, a period in which the Gulf War broke out, followed by the third oil price crisis. Periods of GDP decline always coincide with dematerialization in individual countries. Second, economic recession is significantly correlated with dematerialization, and for low growth conditions (0-3% growth rate), the higher the GDP growth, the less significant we found the correlation with DMC to be, implying that dematerialization is possible in times of economic growth, but confined within a 2% GDP growth rate. Third, with regard to the four categories of material use, construction minerals and metals, both used to construct stocks of buildings and infrastructure, react more strongly to economic fluctuations than the throughput-dominated flows of biomass and fossil fuels. Overall, the findings illustrate the essential role of recession in dematerialization, although this does not mean that recessions are a socially and economically sustainable instrument to control human impact on the environment.

Chapter 4 is my initial attempt at investigating under what conditions and to what extent shorter working hours improve the environment. This study has two objectives. First, to test and confirm the positive correlation between working hours and environmental pressure, i.e., whether less working hours are good for the environment. Second, to check if this positive correlation changes under specific conditions, following Nørgård's (2013, p.67) hint that "more leisure time does not guarantee a lower environmental impact”, and “the extra leisure time will tend to require more energy”. My hypothesis is based on the proverb that “things will develop in the opposite direction when they become extreme”. Therefore, I hypothesize that an excessive reduction in working time may backfire. To this end, first I split the EU-15 into Western, Southern, and Northern countries, based on the fact that they are different in income and lifestyle, which may be the determinant factors in my analysis; second, to examine the change of the nexus over time, I split the research period into two equal phases, i.e., 1970–1990 and 1991–2010; lastly, to make the results more robust, except the commonly-used carbon emissions indicator, I also employ energy consumption as a dependent variable. Using an advanced dynamic panel data approach, sys-GMM (see section 1.3.1 for a detailed explanation of this method), I confirm the significantly positive sign of the working time-environment nexus in Western Europe and Southern Europe when setting carbon emissions as a dependent variable. In the phased regressions, however, Northern Europe shows no significant correlation; Southern Europe shows a significant sign only in the second phase (1991–2010); and the significant relations for Western Europe change from positive to negative. These results confirm my hypothesis that the positive correlation between WTR and environmental pressure only exists in certain cases and under certain conditions.

Chapter 5 advances four areas compared to *Chapter 4*. First, by removing P from the right-hand side of $I = PAT$ model and divide I by P, I can use carbon emissions per capita as the dependent variable, rather than the commonly-used aggregate carbon emissions (O’Neill et al., 2012; Liddle, 2015, p.68); to the best of my knowledge, this is the first such study in the WTR literature. Second, prior studies employ as a research sample either only advanced countries (Knight et al., 2013), or an aggregate of all countries (Hayden and Shandra, 2009), and this may bias the result. In this study, I attempt to expand my sample by using the best data available. I include 55 economies in my analysis, and I apply different tests to developed (37) and to developing (18) countries. Third, rather than arbitrarily and ex-ante dividing the research period into two equivalent sub-periods, as I did in *Chapter 4*, I locate ex-post a breaking point in the year 2000, where environmental burden increases, even when working hours per worker keep decreasing. Fourth, I use an interaction technique to compare the difference of the two subperiods. Based on these improvements, I find that developed economies show significant positive correlation during the first subperiod (1980–2000), which then turns to negative over the second subperiod (2001–2010), while there are no significant effects for developing ones. Underlying reason for this “rebound” may be that certain leisure activities are more energy intensive, as is the case with long-distance traveling, and this may aggravate environmental burden if the working time is reduced beyond a certain level.

Chapter 6 is a follow-up of my previous two papers on working time reduction. Since we already know that shorter working week does not necessarily lead to environmental alleviation, then the questions we have to pose are when (or, at what point) reduced working time harms the environment, and what countries already demonstrate negative environmental effects due to WTR policies. To answer these questions, we need an econometric tool which can accurately estimate the breaking point and split the sample into different country groups. Among the numerous econometric methods, the panel threshold model has three advantages: First, it can estimate the non-linear relations which correspond to the reality that environmental indicators (i.e., carbon emissions and energy use in this study) of almost all EU-15 countries witnessed fluctuations, while working hours generally experienced a declining trend across the whole research period. Second, breaking points (or “threshold values” in the panel threshold model) of working time are endogenously estimated, which could prevent the arbitrary classification of the sample carried out in *Chapters 4* and *5*. Third, sampled countries are automatically grouped into different classes, and the correlations of working time and environmental pressure among these classes can be compared. A detailed explanation of this method is offered in section 1.3.1. The findings reveal that in at least four EU-15 countries where working hours are too low, namely France, Denmark, Germany and the Netherlands, further reductions are likely to harm the environment. By contrast, Greece, having the longest working hours, still has potential to abate its environmental burden by reducing working hours.

7.2 Implications for research and policy

Recession has conventionally been considered a significant research topic in economic domains, therefore most of the studies on recession have focused on its impact on macroeconomic and financial variables, such as employment and credit (Claessens et al., 2009; Bordo & Haubrich

2010), and little systematic empirical research has been dedicated to uncovering how environmental burdens develop in times of recession. *Chapters 2* and *3* quantitatively examine the effects of recession on two representative environmental indicators, i.e., carbon emissions and material consumption, comparing how the two indicators vary in and out of periods of recession. I focus on the possibilities of decarbonization and dematerialization by studying periods characterized by negative economic growth. If low growth or even nongrowth becomes the new norm in the post-financial crisis era, then an analysis of how to meet the Paris commitment under such a degrowth scenario is necessary. My research shows that recessions have limited effects on carbon emissions and a small role to play in their mitigation, but persistent lower than normal growth can make a significant contribution. I have not found any evidence to suggest that recessions backfire or that their positive effects are annulled by negative effects in the long run. In regard to material consumption, future research should shed light on the long-run effects of economic recession and examine whether and how much material use rebounds after recessions or returns to the previous levels with a lag. Estimations of the effects of energy policies on material use, particularly in regard to the four specific types of material, can also be relevant for policy makers.

Future research on WTR policies (*Chapters 4, 5* and *6*) could integrate insights about well-being, or happiness/life satisfaction (Pouwels et al. 2008). The ultimate goal of human development is well-being. Attention in related literature has generally focused on the driving forces of well-being, such as income (Easterlin 2001; Frank 2004). Yet, there is less research on policy drivers such as WTR. Generally, two different explanations are offered on how well-being is affected by working time. First, a redistribution of working time and leisure time changes people's daily routines and living habits, so their evaluation of life satisfaction changes (improves or decreases) accordingly. Specifically, on the one hand, a shorter workweek tends to enhance job satisfaction, and, consequently, well-being increases (Radcliff 2005); On the other hand, an increase in time outside of paid work allows people to engage in personally meaningful activities which can be beneficial for their well-being, such as volunteering (Thoits & Hewitt 2001), or stay with family and relatives (Becchetti et al. 2012). The effect on well-being, be it positive or negative, varies according to different situations. Another explanation relates to income. As inequality is detrimental to well-being, closing the gap between rich and poor may be a way of enhancing well-being (Alesina et al. 2004). A shorter working week is a step in this direction, since a reduction in working time reduces the income of richer people and shared job positions provide an income for the workless. In this way, income is more equally distributed and well-being improves, as a decrease in inequality is strongly associated with shorter working hours (Bowles & Park 2005).

In light of this, two research questions can be formulated: First, does the significant correlation between working hours and well-being persist for a specific country or region, after considering other potential influencing factors, such as income? Second, do preferences regarding WTR policies depend on gender, for example on how many hours of work women or men require to achieve well-being? In this manner, we may shed new light on what contributes to an increase of well-being and on why increased income gradually loses its capacity to promote well-being. A survey well suited for this research direction is the World Values Survey (WVS, www.worldvaluessurvey.org), a global research project exploring people's values and beliefs in almost 100 countries worldwide, using a common questionnaire. The 7th wave started in 2015 and its research period spans from 2016 to 2018; this could help determine people's attitudes towards the factors that affect their feeling of well-being.

A number of policy implications can be derived from this thesis.

First, considering the fact that the rate of economic growth has a significant effect on carbon emissions, compared to other driving forces such as technology advances and renewable energies, it follows that the slower the growth and the earlier we transition to a steady economy, the more effective our efforts towards absolute decarbonization are likely to be, if we are to achieve the Paris Agreement objective of keeping global temperature rise this century well below 2 ℃. My research provides a solid empirical foundation for degrowth, which proposes a downscaling of production and consumption as means to achieve environmental sustainability. A positive sign is that such research and ideas, along with degrowth as a movement, are attracting policy interest, as attested by the recent open debate at the UK House of Commons (Demaria 2017).

Second, absolute dematerialization at the national level occurs almost exclusively during periods of economic recession or low growth. In other words, there is a tension between the goal of economic growth and goals of environmental sustainability; dematerialization comes at the price of economic decline, which under the current social and economic conditions is often a disaster.

However, Tim Jackson envisions a flourishing society without growth, in which GDP is no longer a key measuring indicator for prosperity; where environmental improvement, social justice and happiness can be achieved in a non-growing economy (Jackson 2009). In accord with the above, it is conceivable that an absolute decline in material use due to low, zero or negative growth can promote a prosperous society, with a virtuous cycle coming into effect. In this way, recession, when it is well managed and socially sustainable, no longer has to be seen as the "high price" to pay for dematerialization.

Third, short working hours do not necessarily lead to environmental alleviation if rich communities chose to spend their leisure time in carbon-intensive activities. Policy makers in certain countries with very low working time may consider prolonging the working hours if environmental damages are to be minimized. Alternatively, they might want to keep working time at its current level, but tax resource use and carbon consumption, so as to deter people from having resource-intensive or carbon-intensive activities in their leisure time.

References

Agnarsson, S., 2000. *Productivity in the Icelandic fish processing industry 1985-1995 : a comparison of methods*, Reykjavik.

Ai, C. & Norton, E.C., 2003. Interaction terms in logit and probit models. *Economics Letters*, 80, pp.123–129.

Aichele, R. & Felbermayr, G., 2014. Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade. *Review of Economics and Statistics*, 96(3), pp.402–417.

Akenji, L. et al., 2016. Ossified materialism: introduction to the special volume on absolute reductions in materials throughput and emissions. *Journal of Cleaner Production*.

Alcott, B., 2010. Impact caps: why population , affluence and technology strategies should be abandoned. *Journal of Cleaner Production*, 18(6), pp.552–560. Available at: http://dx.doi.org/10.1016/j.jclepro.2009.08.001.

Alesina, A., Di Tella, R. & MacCulloch, R., 2004. Inequality and happiness: Are Europeans and Americans different? *Journal of Public Economics*, 88(9–10), pp.2009–2042.

Allwood, J.M. et al., 2012. *Sustainable Materials: With both eyes open*, Cambridge: UIT.

Altavilla, C., Garofalo, A. & Vinci, C.P., 2005. Evaluating the effects of working hours on employment and wages. *Journal of Policy Modeling*, 27(6), pp.647–664.

Anderson, K., 2015. Duality in climate science. *Nature Geoscience*, 8(12), pp.1–2. Available at: http://www.nature.com/doifinder/10.1038/ngeo2559.

Andreoni, V. & Galmarini, S., 2014. How to increase well-being in a context of degrowth. *Futures*, 55, pp.78–89. Available at: http://dx.doi.org/10.1016/j.futures.2013.10.021.

Andrews, D.W.K. & Ploberger, W., 1994. Optimal Tests when a Nuisance Parameter is Present Only Under the Alternative. *Econometrica*, 62(6), pp.1383–1414.

Anon, 2016. *Global material flows and resource productivity. Authors: Heinz Schandl, Marina Fischer-Kowalski, Jim West, Stefan Giljum, Monika Dittrich, Nina Eisenmenger, Arne Geschke, Mirko Lieber, Hanspeter Wieland, Anke Schaffartzik, Fridolin Krausmann, Sylvia Gier*, Nairobi.

Arellano, M. & Bond, S., 1991. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *The Review of Economic Studies*, 58(2), pp.277–297.

Artazcoz, L. et al., 2016. Long working hours and health in Europe : Gender and welfare state differences in a context of economic crisis. *Health & Place*, 40, pp.161–168.

Asara, V. et al., 2015. Socially sustainable degrowth as a social–ecological transformation: repoliticizing sustainability. *sustainability science*, 10, pp.375–384.

Ashford, B.N.A. & Kallis, G., 2013. A Four-day Workweek : A Policy for Improving Employment and Environmental Conditions in Europe. *The European Financial Review*, pp.53–58.

Askenazy, P., 2013. Working time regulation in France from 1996 to 2012. *Cambridge Journal of Economics*, 37(2), pp.323–347.

Ausubel, J.H. & Waggoner, P.E., 2008. Dematerialization: Variety, caution, and persistence. In *Proceedings of the National Academy of Sciences of the United States of America*. pp. 12774–12779. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2525557&tool=pmcentrez&rendertype=abstract.

Bachman & Paternoster, 1997. *Statistics for criminology and criminal justice*, Boston: McGraw-Hill.

Bakas, D. & Papapetrou, E., 2014. Unemployment in Greece: Evidence from Greek regions using panel unit root tests. *Quarterly Review of Economics and Finance*, 54(4), pp.551–562. Available at: http://dx.doi.org/10.1016/j.qref.2014.03.002.

Baltagi, B.H., 2005. *Econometric Analysis of Panel Data* Third Edit., John Wiley & Sons, Ltd.

Barbier, E.B., 2010. Global governance: the G20 and a global green new deal. *Economics*, 4.

Barro, R.J. & Ursúa, J.F., 2008. Macroeconomic Crises since 1870. *Brookings Papers on Economic Activity*, 2008(1), pp.255–350.

Baum, S.D. & Handoh, I.C., 2014. Integrating the planetary boundaries and global catastrophic risk paradigms. *Ecological Economics*, 107, pp.13–21. Available at: http://dx.doi.org/10.1016/j.ecolecon.2014.07.024.

Bayer, P., Dolan, L. & Urpelainen, J., 2013. Global patterns of renewable energy innovation, 1990-2009. *Energy for Sustainable Development*, 17(3), pp.288–295. Available at: http://dx.doi.org/10.1016/j.esd.2013.02.003.

Becchetti, L., Giachin, E. & Pelloni, A., 2012. The relationship between social leisure and life satisfaction: Causality and Policy Implications. *Social Indicators Research*, 108(3), pp.453–490.

Behrens, A. et al., 2007. The material basis of the global economy Worldwide patterns of natural resource extraction and their implications for sustainable resource use policies. *Ecological Economics*, 64, pp.444–453.

Bel, G. & Joseph, S., 2014. *" Industrial Emissions Abatement : Untangling the Impact of the EU ETS and the Economic Crisis ,"* Barcelona.

van den Bergh, J. & Grazi, F., 2014. Response to Wackernagel. *Journal of Industrial Ecology*, 18(1), pp.23–25. Available at: http://doi.wiley.com/10.1111/jiec.12096.

van den Bergh, J.C.J.. & Grazi, F., 2014. Ecological Footprint Policy? Land Use as an Environmental Indicator. *Journal of Industrial Ecology*, 18(1), pp.10–19. Available at: http://doi.wiley.com/10.1111/jiec.12045 [Accessed June 22, 2014].

Bergh, J.C.J.M. van den, 2011. Energy Conservation More Effective With Rebound Policy. *Environmental and Resource Economics*, 48(1), pp.43–58.

van den Bergh, J.C.J.M., 2011. Environment versus growth — A criticism of "degrowth" and a plea for "a-growth." *Ecological Economics*, 70(5), pp.881–890. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800910004209 [Accessed July 9, 2014].

van den Bergh, J.C.J.M. & Kallis, G., 2012. Growth , A-Growth or Degrowth to Stay within Planetary Boundaries ? *Journal of economic issues*, XLV I(4), pp.909–920.

Bergoeing, R. et al., 2002. A Decade Lost and Found : Mexico and Chile in the 1980s. *Review of Economic Dynamics*, 5(1), pp.166–205.

Blank, B.R.M., 2014. The Role of Part-Time Work in Women's Labor Market Choices Over Time. *The American Economic Review*, 79(2), pp.295–299. Available at: http://www.jstor.org/stable/1827773.

Blundell, R. & Bond, S., 1998. Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, 87(1), pp.115–143. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0304407698000098.

Bordo, M.D. & Haubrich, J.G., 2010. Credit crises, money and contractions: An historical view. *Journal of Monetary Economics*, 57(1), pp.1–18. Available at: http://dx.doi.org/10.1016/j.jmoneco.2009.10.015.

Bourrelle, J.S., 2014. Zero energy buildings and the rebound effect : A solution to the paradox of energy efficiency ? *Energy & Buildings*, 84, pp.633–640. Available at: http://dx.doi.org/10.1016/j.enbuild.2014.09.012.

Bowen, A. et al., 2009. *The implications of the economic slowdown for greenhouse gas emissions and targets*, Leeds.

Bowen, A. & Fankhauser, S., 2011. The green growth narrative: Paradigm shift or just spin? *Global Environmental Change*, 21, pp.1157–1159.

Bowen, A. & Stern, N., 2010. Environmental policy and the economic downturn. *Oxford Review of Economic Policy*, 26(2), pp.137–163.

Bowles, S. & Park, Y., 2005. Emulation, inequality , and work hours : was Thorsten Veblen right? *The Economic Journal*, 115, pp.397–412.

BP, 2016. *BP Statistical Review of World Energy*, London.

Brana, S. & Prat, S., 2016. The effects of global excess liquidity on emerging stock market returns: Evidence from a panel threshold model. *Economic Modelling*, 52, pp.26–34. Available at: http://dx.doi.org/10.1016/j.econmod.2015.06.026.

Breuer, J.B. & McDermott, J., 2013. Economic depression in the world. *Journal of Macroeconomics*, 38(PB), pp.227–242. Available at: http://dx.doi.org/10.1016/j.jmacro.2013.07.003.

Bringezu, S. et al., 2004. International comparison of resource use and its relation to economic growth: The development of total material requirement, direct material inputs and hidden flows and the structure of TMR. *Ecological Economics*, 51(1–2), pp.97–124.

Browne, D., Regan, B.O. & Moles, R., 2011. Material fl ow accounting in an Irish city-region 1992 e 2002. *Journal of Cleaner Production*, 19(9–10), pp.967–976. Available at: http://dx.doi.org/10.1016/j.jclepro.2011.01.007.

Burke, P.J., Shahiduzzaman, M. & Stern, D.I., 2015. Carbon dioxide emissions in the short run: The rate and sources of economic growth matter. *Global Environmental Change*, 33, pp.109–121.

Chan, K.S., 1993. Consistency and Limiting Distribution of the Least Squares Estimator of a Threshold Autoregressive Model. *The Annals of Statistics*, 21(1), pp.520–533.

Chang, C.-L., Khamkaew, T. & McAleer, M., 2009. *A Panel Threshold Model of Tourism Specialization and Economic Development*, Tokyo. Available at: http://www.cirje.e.u-tokyo.ac.jp/research/dp/2009/2009cf685.pdf.

Chang, H., Dong, X. & MacPhail, F., 2011. Labor Migration and Time Use Patterns of the Left-behind Children and Elderly in Rural China. *World Development*, 39(12), pp.2199–2210.

Chazan, D., 2016. France reviews its 35-hour working week. *Telegraph*, p.1. Available at: http://www.telegraph.co.uk/news/worldnews/europe/france/12120927/France-reviews-its-35-hour-working-week.html.

Che, C.M., 2013. Panel threshold analysis of Taiwan's outbound visitors. *Economic Modelling*, 33, pp.787–793. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0264999313002228 [Accessed June 26, 2014].

Ben Cheikh, N. & Louhichi, W., 2016. Revisiting the role of inflation environment in exchange rate pass-through: A panel threshold approach. *Economic Modelling*, 52, pp.233–238. Available at: http://dx.doi.org/10.1016/j.econmod.2014.11.004.

Cheon, A. & Urpelainen, J., 2012. Oil prices and energy technology innovation : An empirical analysis. *Global Environmental Change*, 22(2), pp.407–417.

Chitnis, M. et al., 2014. Who rebounds most ? Estimating direct and indirect rebound effects for different UK socioeconomic groups. *Ecological Economics*, 106, pp.12–32. Available at: http://dx.doi.org/10.1016/j.ecolecon.2014.07.003.

Claessens, S., Kose, M.A. & Terrones, M.E., 2009. What happens during recessions, crunches and busts? *Economic Policy*, pp.653–700.

Cole, H.L. & Ohanian, L.E., 2002. The Great U.K. Depression: A Puzzle and Possible Resolution. *Review of Economic Dynamics*, 5(1), pp.19–44.

Coote, A., Franklin, J., Simms, A., 2010. *21 hours: Why a shorter working week can help us all to flourish in the 21st century*, London: New Economics Foundation.

D'Alisa, G. & Cattaneo, C., 2013. Household work and energy consumption: a degrowth perspective. Catalonia's case study. *Journal of Cleaner Production*, 38, pp.71–79. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652611004975 [Accessed May 30, 2014].

Dahl, C.M. & Gonzalez-Rivera, G., 2003. Testing for neglected nonlinearity in regression models based on the theory of random fields. *Journal of Econometrics*, 114, pp.141–164.

Dang, V.A., Kim, M. & Shin, Y., 2012. Asymmetric capital structure adjustments: New evidence from dynamic panel threshold models. *Journal of Empirical Finance*, 19(4), pp.465–482. Available at: http://dx.doi.org/10.1016/j.jempfin.2012.04.004.

Davies, R.B., 1987. Hypothesis testing when a nuisance parameter is present only under the alternative. *Biometrika*, 74(1), pp.33–43.

Declercq, B., Delarue, E. & D'haeseleer, W., 2011. Impact of the economic recession on the European power sector's CO2 emissions. *Energy Policy*, 39(3), pp.1677–1686. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421510009432.

Demaria, F., 2017. When degrowth enters the parliament. *The Ecologist*, p.2. Available at: http://www.theecologist.org/blogs_and_comments/commentators/2988542/when_degrowth_enters_the_parliament.html.

Devetter, F.-X. & Rousseau, S., 2011. Working Hours and Sustainable Development. *Review of Social Economy*, 69(3), pp.333–355.

Diamond, M.L. et al., 2015. Exploring the planetary boundary for chemical pollution. *Environment International*, 78, pp.8–15. Available at: http://dx.doi.org/10.1016/j.envint.2015.02.001.

Dietz, T. & Rosa, E. a, 1997. Effects of population and affluence on CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America*, 94(1), pp.175–9. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12467373.

Dinda, S., 2004. Environmental Kuznets Curve hypothesis: A survey. *Ecological Economics*, 49(4), pp.431–455.

Doda, B., 2014. Evidence on business cycles and emissions. *Journal of Macroeconomics*, 40, pp.214–227. Available at: http://linkinghub.elsevier.com/retrieve/pii/S016407041400007X.

Doytch, N. & Uctum, M., 2011. Does the worldwide shift of FDI from manufacturing to services accelerate economic growth? A GMM estimation study. *Journal of International Money and Finance*, 30(3), pp.410–427. Available at: http://dx.doi.org/10.1016/j.jimonfin.2011.01.001.

Druckman, A. et al., 2012. Time, gender and carbon: A study of the carbon implications of British adults' use of time. *Ecological Economics*, 84, pp.153–163. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800912003709 [Accessed June 18, 2014].

Easterlin, R.A., 2001. Income and happiness: Towards a unified theory. *Economic Journal*, 111(473), pp.465–484.

EEA, 2011. Recession accelerates the decline in EU greenhouse gas emissions. *European Environment Agency*, pp.3–4. Available at: http://www.eea.europa.eu/highlights/recession-accelerates-the-decline-in.

Ehrlich, P. R. and Holdren, J.P., 1971. Impact of Population Growth. *Science*, 171(3977), pp.1212–1217. Available at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:No+Title#0 [Accessed June 28, 2014].

EIA, 2016. U.S. Energy Information Administration. *U.S. Energy Information Administration*. Available at: http://www.eia.gov/ [Accessed June 14, 2016].

Enevoldsen, M.K., Ryelund, A. V. & Andersen, M.S., 2007. Decoupling of industrial energy consumption and CO2-emissions in energy-intensive industries in Scandinavia. *Energy Economics*, 29(4), pp.665–692. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0140988307000138 [Accessed July 20, 2014].

Estev ão, M. & S á, F., 2008. The 35-hour workweek in France: Straightjacket or welfare improvement? *Economic Policy*, (July), pp.417–463.

Everett, T. et al., 2010. *Economic growth and the environment*, Available at: http://qje.oxfordjournals.org/content/110/2/353.short.

Fang, K., Heijungs, R. & Snoo, G.R. De, 2015. Understanding the complementary linkages between environmental footprints and planetary boundaries in a footprint–boundary environmental sustainability assessment framework. *Ecological Economics*, 114, pp.218–226.

Feenstra, R.C., Inklaar, R. & Timmer, M.P., 2015. The Next Generation of the Penn World Table. *American Economic Review*, 105(10), pp.3150–82.

Felbermayr, G.J., 2005. Dynamic Panel Data Evidence on the Trade-Income Relation. *Review of World Economics*, 141(4), pp.583–611. Available at: http://link.springer.com/10.1007/s10290-005-0046-4 [Accessed June 28, 2014].

Feng, K. et al., 2015. Drivers of the US CO2 emissions 1997-2013. *Nature Communications*, 6(7714), p.8. Available at: http://www.nature.com/ncomms/2015/150721/ncomms8714/abs/ncomms8714.html.

Fiala, N., 2008. Measuring sustainability: Why the ecological footprint is bad economics and bad environmental science. *Ecological Economics*, 67(4), pp.519–525.

Fischer-Kowalski, M. et al., 2011. Methodology and indicators of economy-wide material flow accounting: State of the art and reliability across sources. *Journal of Industrial Ecology*, 15(6), pp.855–876.

Fischer-Kowalski, M. & Schaffartzik, A., 2015. Energy availability and energy sources as determinants of societal development in a long-term perspective. *MRS Energy & Sustainability - A Review Journal*, 2.

Fisher, J.D.M. & Hornstein, A., 2002. The Role of Real Wages, Productivity, and Fiscal Policy in Germany's Great Depression 1928–1937. *Review of Economic Dynamics*, 5(1), pp.100–127.

Fishman, T. et al., 2014. Accounting for the Material Stock of Nations. *Journal of Industrial Ecology*, 18(3), pp.407–420.

Fitzgerald, J.B., Jorgenson, A.K. & Clark, B., 2015. Energy consumption and working hours: a longitudinal study of developed and developing nations, 1990–2008. *Environmental Sociology*, (June 2015), pp.1–11. Available at: http://www.tandfonline.com/doi/full/10.1080/23251042.2015.1046584.

Frank, R.H., 2004. How not to buy happiness. *Dædalus*, 27(1995), pp.69–79.

Galeotti, M., Lanza, A. & Pauli, F., 2006. Reassessing the environmental Kuznets curve for CO2 emissions: A robustness exercise. *Ecological Economics*, 57(1), pp.152–163.

GCA, 2016. Global Carbon Atlas. *Global Carbon Atlas*. Available at: http://www.globalcarbonatlas.org/?q=en/content/welcome-carbon-atlas [Accessed January 1, 2016].

Georgescu-roegen, N., 1971. *The Entropy Law and the Economic Process,* Cambridge: Harvard University Press.

Georgescu-roegen, N., 1987. *The Entropy Law and the Economic Process in Retrospect*,

Ghosh, N.K. & Blackhurst, M.F., 2014. Energy savings and the rebound effect with multiple energy services and ef fi ciency correlation. *Ecological Economics*, 105, pp.55–66. Available at: http://dx.doi.org/10.1016/j.ecolecon.2014.05.002.

Giang, D.T.H. & Sui Pheng, L., 2011. Role of construction in economic development: Review of key concepts in the past 40 years. *Habitat International*, 35(1), pp.118–125.

Gilchrist, S., Himmelberg, C.P. & Huberman, G., 2005. Do stock price bubbles influence corporate investment ? *Journal of Monetary Economics*, 52, pp.805–827.

Gómez-Baggethun, E. & Naredo, J.M., 2015. In search of lost time: the rise and fall of limits to growth in international sustainability policy. *Sustainability Science*, 10(3), pp.385–395.

Gorz, A., 1994. *Capitalism, Socialism. Ecology*, London: Verso.

Gorz, A., 1982. *Farewell to the working class. An essay on Post-Industrialism*, London: Pluto Press.

Grape, E. & Kolm, A.-S., 2014. Short-time work—Some long-run implications. *Economics Letters*, 124(1), pp.30–32.

Hansen, B.E., 1999. Threshold effects in non-dynamic panels: Estimation, testing, and inference. *Journal of Econometrics.*, 93(2), pp.345–368.

Hansen, L.P. & Singleton, K.J., 1982. Generalized Instrumental Variables Estimation of Nonlinear Rational Expectations Models. *Econometrica*, 50(5), pp.1269–1286.

Hassett, B.K.A. & Strain, M.R., 2014. *Worksharing and Long-Term Unemployment*,

Hayashi, F. & Prescott, E.C., 2002. The 1990s in Japan: A Lost Decade. *Review of Economic Dynamics*, 5(1), pp.206–235. Available at: http://www.sciencedirect.com/science/article/pii/S1094202501901498.

Hayden, A., 1999. *Sharing the Work, Sparing the Planet: Work Time, Consumption, & Ecology*, London & New York: Zed Books; Toronto, Between the Lines; Sydney, Pluto Press.

Hayden & Shandra, J.M., 2009. Hours of work and the ecological footprint of nations: an exploratory analysis. *Local Environment: The International Journal of Justice and Sustainability*, 14(6), pp.575–600. Available at: http://www.tandfonline.com.are.uab.cat/doi/pdf/10.1080/13549830902904185#.VX7_atyUfUI.

Hermann, C., 2015. *Capitalism and the political ecology of work time*, London & New York.

Holtz-Eakin, D., Newey, W. & Rosen, H.S.., 1988. Estimating Vector Autoregressions with Panel Data. *Econometrica*, 56(6), pp.1371–1395.

Hsiao, C., 2003. *Analysis of panel data* Second edi., Cambridge University Press.

Hunt, J., 1998. Hours Reductions as Work-Sharing. *Brookings Paper on Economic Activity*, 1.

IEA, 2016. International Energy Agency.

IEA, 2012. *World Energy Outlook*, Paris.

IMF, 2013. *Energy Subsidy Reform: Lessons and Implications*, Available at: http://books.google.com/books?hl=en&lr=&id=NYi1AQAAQBAJ&oi=fnd&pg=PP2&dq=ENERGY+SUBSIDY+REFORM+:+LESSONS+AND+IMPLICATIONS&ots=4saeQWH9da&sig=dm4_xQDUGapysuN1PCO3mbUJB_g.

IPCC, 2014. *Climate Change 2014: Synthesis Report.Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Geneva, Switzerland. Available at: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf.

Jackson, T., 2009. *Prosperity without growth: Economics for a finite planet*, London: Earthscan.

Kallis, G. et al., 2013. “Friday off”: Reducing Working Hours in Europe. *Sustainability*, pp.1545–1567.

Kallis, G., 2011. In defence of degrowth. *Ecological Economics*, 70(5), pp.873–880.

Kallis, G., 2013. Societal metabolism, working hours and degrowth: a comment on Sorman and Giampietro. *Journal of Cleaner Production*, 38, pp.94–98.

Kallis, G., D’Alisa, G. & Demaria, F., 2014. Introduction: degrowth. In *Degrowth: A vocabulary for a new era*. London: Routledge. Available at: http://www.tandfonline.com/doi/abs/10.1080/10455752.2011.648836.

Kallis, G., Demaria, F. & D’Alisa, G., 2014. *Degrowth : A Vocabulary for a New Era* 1st ed., Barcelona. Available at: https://www.researchgate.net/publication/271506217.

Kallis, G., Kerschner, C. & Martinez-alier, J., 2012. The economics of degrowth. *Ecological Economics*, pp.1–9. Available at: http://dx.doi.org/10.1016/j.ecolecon.2012.08.017.

Kehoe, T.J. & Prescott, E.C., 2002. Great Depressions of the 20th Century. *Review of Economic Dynamics*, 5(1), pp.1–18. Available at: http://www.sciencedirect.com/science/article/pii/S1094202501901516.

King, L.C. & van den Bergh, J.C.J.., 2017. Worktime Reduction as a Solution to Climate Change : Five Scenarios Compared for the UK. *Ecological Economics*, 132, pp.124–134.

Klomp, J. & de Haan, J., 2013. Popular protest and political budget cycles: A panel data analysis. *Economics Letters*, 120(3), pp.516–520. Available at: http://linkinghub.elsevier.com/retrieve/pii/S016517651300267X [Accessed July 3, 2014].

Knight, K.W., Rosa, E. a. & Schor, J.B., 2013. Could working less reduce pressures on the environment? A cross-national panel analysis of OECD countries, 1970–2007. *Global Environmental Change*, 23(4), pp.691–700.

Krausmann, F. et al., 2008. Global patterns of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. *Ecological Economics*, 65(3), pp.471–487.

Krausmann, F. et al., 2009. Growth in global materials use, GDP and population during the 20th century. *Ecological Economics*, 68(10), pp.2696–2705. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800909002158 [Accessed July 10, 2014].

Kuo, C.-S., Li, M.-Y.L. & Yu, S.-E., 2013. Non-uniform effects of CEO equity-based compensation on firm performance – An application of a panel threshold regression model. *The British Accounting Review*, 45(3), pp.203–214. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0890838913000486 [Accessed June 26, 2014].

Kuroda, S., 2010. Do Japanese Work Shorter Hours than before? Measuring trends in market work and leisure using 1976–2006 Japanese time-use survey. *Journal of the Japanese and International Economies*, 24(4), pp.481–502.

Kydland, F.E. & Zarazaga, C.E.J.M., 2002. Argentina`s Lost Decade. *Review of Economic Dynamics*, 5(1), pp.152–165.

Lajeunesse, R., 2009. *Work Time Regulation as a Sustainable Full-Employment Strategy*, Routledge. Available at: http://samples.sainsburysebooks.co.uk/9781134044771_sample_511068.pdf.

Landsburg, S., 2006. Why Europeans Work Less Than Americans. *Forbes*, p.1.

Latouche, S., 2010. Degrowth. *Journal of Cleaner Production*, 18, pp.519–522.

Latouche, S., 2003. Pour une société de décroissance: Le monde diplomatique. *Le Monde Diplomatique*, pp.18–19. Available at: http://www.monde-diplomatique.fr/2003/11/LATOUCHE/10651.

Lee, S., McCann, D. & Messenger, J.C., 2007. *Working Time Around the World*, Available at: http://www.ilo.org/global/about-the-ilo/press-and-media-centre/news/lang--en/WCMS_082827#1.

Leone, A.J., Minutti-meza, M. & Wasley, C., 2013. *Influential Observations and Inference in Accounting Research*,

Lewis, S.L., 2012. we must set planetary boundaries wisely. *Nature*, 485, p.417.

Liddle, B., 2015. What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates. *Global Environmental Change*, 31, pp.62–73. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959378014002040.

Logeay, C. & Schreiber, S., 2004. Evaluating the Effectiveness of the French work-sharing reform. In *EEA2004*.

Mace, G.M. et al., 2014. Approaches to defining a planetary boundary for biodiversity. *Global Environmental Change jo*, 28, pp.289–297.

Martens, M., Kofman, P. & Vorst, T.C.F., 1998. A threshold error-correction model for intraday futures and index returns. *Journal of Applied Econometrics*, 13(3), pp.245–263. Available at: http://onlinelibrary.wiley.com/doi/10.1002/(SICI)1099-1255(199805/06)13:3%3C245::AID-JAE480%3E3.0.CO;2-E/abstract%5Cnhttp://onlinelibrary.wiley.com/doi/10.1002/(SICI)1099-1255(199805/06)13:3%3C245::AID-JAE480%3E3.0.CO;2-E/abstract%5Cnhttp://onlinelibrary.wiley.com/st.

Martínez-alier, J. et al., 2010. Sustainable de-growth : Mapping the context , criticisms and future prospects of an emergent paradigm. *Ecological Economics*, 69(9), pp.1741–1747. Available at: http://dx.doi.org/10.1016/j.ecolecon.2010.04.017.

McDermott, M., 2012. Cheaper Natural Gas Behind 2009 Drop In US Emissions. *TreeHugger*. Available at: http://www.treehugger.com/energy-policy/cheaper-natural-gas-prices-behind-2009-drop-united-states-emissions.html.

Meadows, D., Meadows, D. & Randers, J., 1992. *Beyond the Limits* 1st ed., New York: Chelsea Green Publishing.

Meadows, D., Randers, J. & Meadows, D., 2004. *Limits to Growth: The 30-Year Update*, Vermont: Chelsea Green Publishing Company, White River Junction, VT. Available at: http://www.unice.fr/sg/resources/docs/Meadows-limits_summary.pdf.

Messenger, J.C., 2009. Work sharing: A strategy to preserve jobs during the global jobs crisis. *TRAVAIL Policy Brief No . 1*, (1).

Messenger, J.C. & Ghosheh, N., 2013. An introduction to work sharing: A strategy for preserving jobs, creating new employment and improving individual well-being. In *Work Sharing During The Great Recession: New Developments and Beyond*. Cheltenham, UK: Edward Elgar, pp. 1–23. Available at: http://www.elgaronline.com/view/9781782540878.00005.xml.

Messenger, J.C. & Ghosheh, N., 2012. *Worksharing: New Developments during the Great Recession and Beyond*, Geneva, Switzerland: Conditions of Work and Employment Programme International Labour Organisation.

Mogielnicki, R., 2016. Working shorter hours may be more productive. *The National Opinion*, p.2.

Mommaerts, M., 2009. The European working time directive - Facts and issues. *Journal of Cranio-Maxillofacial Surgery*, 37(2), pp.110–112.

Müller, D.B., 2006. Stock dynamics for forecasting material flows — Case study for housing in The Netherlands. *Ecological Economics*, 59, pp.142–156.

Nässén, J. & Larsson, J., 2015. Would shorter work time reduce greenhouse gas emissions ? An analysis of time use and consumption in Swedish households. *Environment and Planning C: Government and Policy*, 33.

Nässén, J., Larsson, J. & Holmberg, J., 2009. The effect of work hours on energy use: A micro-analysis of time and income effects. In *European council for an energy efficient economy*. pp. 1801–1809.

Nerlove, M., 2002. *Essays in Panel Data Econometrics*, Cambridge: Cambridge University Press. Available at: http://www.newbooks-services.de/MediaFiles/Texts/5/9780521815345_Excerpt_001.pdf.

Nguyen, T., Locke, S. & Reddy, K., 2014. A dynamic estimation of governance structures and financial performance for Singaporean companies. *Economic Modelling*, 40, pp.1–11. Available at: http://dx.doi.org/10.1016/j.econmod.2014.03.013.

Nørgård, J.S., 2013. Happy degrowth through more amateur economy. *Journal of Cleaner Production*, 38, pp.61–70. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652611005142 [Accessed May 27, 2014].

O'Neill, B.C. et al., 2012. Demographic change and carbon dioxide emissions. *The Lancet*, 380(9837), pp.157–164. Available at: http://dx.doi.org/10.1016/S0140-6736(12)60958-1.

Obani, P.C. & Gupta, J., 2015. The impact of economic recession on climate change: eight trends. *Climate and Development*, 5529(May), pp.1–13. Available at: http://www.tandfonline.com/doi/abs/10.1080/17565529.2015.1034226#aHR0cDovL3d3dy50YW5kZm9ubGluZS5jb20vZG9pL3BkZi8xMC4xMDgwLzE3NTY1NTI5LjIwMTUuMTAzNDIyNkBAQDA=.

OECD, 2014. Green growth in action: Germany. , p.1. Available at: http://www.oecd.org/germany/greengrowthinactiongermany.htm [Accessed May 30, 2016].

OECD, 2016. OECD Statistics. *OECD*. Available at: http://stats.oecd.org/ [Accessed June 14, 2016].

OECD, 2011. *Towards Green Growth: A summary for policy makers May 2011*, Paris. Available at: https://www.oecd.org/greengrowth/48012345.pdf.

Oltermann, P., 2017. Sweden sees benefits of six-hour working day in trial for care workers. *The Guardian*, p.2. Available at: https://www.theguardian.com/world/2017/jan/04/sweden-sees-benefits-six-hour-working-day-trial-care-workers.

Pacala, S., 2004. Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science*, 305(5686), pp.968–972. Available at: http://www.sciencemag.org/cgi/doi/10.1126/science.1100103.

Park, J., Kwon, O.J. & Kim, Y., 2012. Long Working Hours in Korea — Results of The 2010 Working Conditions Survey. *Industrial Health*, (50), pp.458–462.

Parker, L., Blodgett, J. & Yacobucci, B.D., 2011. *U . S . Global Climate Change Policy : Evolving Views on Cost , Competitiveness , and Comprehensiveness*, Washington, DC.

Paroussos, L. et al., 2014. Assessment of carbon leakage through the industry channel: The EU perspective. *Technological Forecasting and Social Change*. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0040162514000602 [Accessed May 29, 2014].

Perc, M. et al., 2012. Evolutionary dynamics of group interactions on structured populations: A review. *Journal of the Royal Society*, Interface, pp.1–17. Available at: http://dx.doi.org/10.1098/rsif.2012.0997.

Perc, M. & Szolnoki, A., 2010. Coevolutionary games – a mini review. *Biosystems*, 99, pp.109–125.

Perlow, L., 1996. the Time Famine: Towards a Sociology of Work Time. *Academy of Management Best Papers Proceedings*, 8(1), pp.244–248.

Pesaran, M.H., 2004. General Diagnostic Tests for Cross Section Dependence in Panels. , (1229). Available at: http://www.dspace.cam.ac.uk/handle/1810/446.

Peters, G.P. et al., 2012. Rapid growth in CO2 emissions after the 2008 – 2009 global financial crisis. *Nature Climate Change*, 2, pp.2–4.

Potter, S.M., 1995. A Nonlinear Approach to US GNP. *Journal of Applied Econometrics*, 10(2), pp.109–125.

Pouwels, B., Siegers, J. & Vlasblom, J.D., 2008. Income, working hours, and happiness. *Economics Letters*, 99(1), pp.72–74.

Prescott, E.C., Rogerson, R. & Wallenius, J., 2009. Lifetime aggregate labor supply with endogenous workweek length. *Review of Economic Dynamics*, 12(1), pp.23–36.

Presidential Commission on Green Growth, 2009. *Road to Our Future: Green Growth. National Strategy and the Five-Year Plan (2009~2013).*, Seoul.

Pullinger, M., 2014. Working time reduction policy in a sustainable economy: Criteria and options for its design. *Ecological Economics*, 103, pp.11–19.

Radcliff, B., 2005. Class organization and subjective well-being: A cross-national analysis. *Social Forces*, 84, pp.513–530. Available at: http://sf.oxfordjournals.org/content/84/1/513.short.

Rao, B.B., Tamazian, A. & Kumar, S., 2010. Systems GMM estimates of the Feldstein–Horioka puzzle for the OECD countries and tests for structural breaks. *Economic Modelling*, 27(5), pp.1269–1273. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0264999310000349 [Accessed June 28, 2014].

Reddy, S. & Minoiu, C., 2009. Real Income Stagnation of Countries 1960 – 2001 Real Income Stagnation of Countries. *The Journal of Development Studies*, 45(1).

Reid, F., 1982. UI-Assisted Worksharing as an Alternative to Layoffs: The Canadian Experience. *Industrial and Labor Relations Review*, 35(3), pp.319–329.

Rockström, J. et al., 2009. A safe operating space for humanity. *Nature*, 461, pp.472–475.

Rockström, J., 2015. *Bounding the Planetary Future : Why We Need a Great Transition*, Stockholm. Available at: http://www.greattransition.org/publication/bounding-the-planetary-future-why-we-need-a-great-transition.

Rockström, J. & Klum, M., 2015. *Big World, Small Planet: Abundance within Planetary Boundaries* 1st ed. P. Miller, ed., NewHaven: Yale University Press.

Rogers, J., 2017. Sweden tries to force 30 hour working week but scraps it after it turns into a DISASTER. *Express*, p.2. Available at: http://www.express.co.uk/news/world/750037/Sweden-six-hour-working-day-scrapped-financial-disaster.

Rogich, D.G., 1996. Material use, economic growth, and the environment. *Nonrenewable Resources*, 5(4), pp.197–210.

Roodman, D., 2010. How to do xtabond2: An introduction to difference and system GMM in Stata. *The Stata Journal*, 10(3), pp.288–308. Available at: http://ideas.repec.org/a/tsj/stataj/v7y2007i4p465-506.html.

Rosnick, D., 2013. Reduced work hours as a means of slowing climate change. *Real-world Economics Review*, (63), pp.124–135.

Rosnick, D. & Weisbrot, M., 2006. Are Shorter Work Hours Good for the Environment ? A Comparison of US and European Energy Consumption. *Center for Economic and Policy Research (CEPR),Cambridge, MA.*

Rothbard, M.N., 2000. *America's Great Depression* 5th ed., Auburn,Alabama: The Ludwig von Mises Institute.

Rothbard, M.N., 2009. *Economic Depressions: Their Cause and Cure*, the Ludwig von Mises Institute.

Russi, D. et al., 2008. Material Flows in Latin America. *Journal of Industrial Ecology*, 12(5–6), pp.704–720. Available at: http://doi.wiley.com/10.1111/j.1530-9290.2008.00074.x [Accessed July 20, 2014].

Schaffartzik, A., Eisenmenger, N., et al., 2014. Consumption-based Material Flow Accounting. *Journal of Industrial Ecology*, 18(1), pp.102–112. Available at: http://doi.wiley.com/10.1111/jiec.12055 [Accessed July 20, 2014].

Schaffartzik, A., Mayer, A., et al., 2014. The global metabolic transition: Regional patterns and trends of global material flows, 1950-2010. *Global Environmental Change*, 26(1), pp.87–97. Available at: http://dx.doi.org/10.1016/j.gloenvcha.2014.03.013.

Schneider, F., Kallis, G. & Martinez-alier, J., 2010. Crisis or opportunity ? Economic degrowth for social equity and ecological sustainability . Introduction to this special issue. *Journal of Cleaner Production*, 18(6), pp.511–518. Available at: http://dx.doi.org/10.1016/j.jclepro.2010.01.014.

Schor, J.B., 2005. Sustainable Consumption and Worktime Reduction. In pp. 37–50. Available at: http://doi.wiley.com/10.1162/1088198054084581.

Schor, J.J., 1995. Can the north stop consumption growth? Escaping the cycle of work and spend. In V.Bhaskar and A.Glyn, ed. *The north, the south, and the environment*. London: London: Earthscan.

Schreiber, S., 2008. Did work-sharing work in France? Evidence from a structural co-integrated VAR model. *European Journal of Political Economy*, 24(2), pp.478–490.

Schumacher, I., 2014. An empirical study of the determinants of green party voting. *Ecological Economics*, 105, pp.306–318. Available at: http://dx.doi.org/10.1016/j.ecolecon.2014.05.007.

Sekulova, F. et al., 2013. Degrowth : from theory to practice. *Journal of Cleaner Production*, 38, pp.1–6. Available at: http://dx.doi.org/10.1016/j.jclepro.2012.06.022.

SERI, 2016. The online portal for material flow data. Available at: http://www.materialflows.net/ [Accessed December 8, 2016].

Shao, Q., 2015. Effect of working time on environmental pressures: empirical evidence from EU-15, 1970–2010. *Chinese Journal of Population Resources and Environment*, (April), pp.1–9. Available at: http://www.tandfonline.com/doi/full/10.1080/10042857.2015.1033803.

Shao, Q. & Rodr ǵuez-labajos, B., 2016. Does decreasing working time reduce environmental pressures ? New evidence based on dynamic panel approach. *Journal of Cleaner Production*, 125, pp.227–235. Available at: http://dx.doi.org/10.1016/j.jclepro.2016.03.037.

Shao, S., Huang, T. & Yang, L., 2014. Using latent variable approach to estimate China′s economy-wide energy rebound effect over 1954–2010. *Energy Policy*, 72, pp.235–248. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421514002766 [Accessed July 2, 2014].

Smedley, T., 2014. Workless or work less: would a shorter working week be better for all of us? *The Guardian*, p.2.

Sonnenschein, J. & Mundaca, L., 2016. Decarbonization under green growth strategies ? The case of South Korea. *Journal of Cleaner Production*, 123(January 2015), pp.180–193. Available at: http://dx.doi.org/10.1016/j.jclepro.2015.08.060.

Spangenberg, J.H. & Lorek, S., 2002. Environmentally sustainable household consumption: From aggregate environmental pressures to priority fields of action. *Ecological Economics*, 43(2–3), pp.127–140.

Spangenberg, J.H., Omann, I. & Hinterberger, F., 2002. Sustainable growth criteria minimum benchmarks and scenarios for employment and the environment. *Ecological Economics*, 42(3), pp.429–443.

Speth, J.G., 2008. *The Bridge at the Edge of the World. Capitalism, the Environment, and the Crossing from Crisis to Sustainability* Conneticut, ed., New Haven: Yale University Press.

Statistics Finland, 2014. *Economy-wide Material Flow Accounts*, Helsinki. Available at: http://seri.at/wp-content/uploads/2009/08/SERI-BP2.pdf.

Steinberger, J.K. et al., 2013. Development and Dematerialization: An International Study. *PLoS ONE*, 8(10), p.e70385.

Steinberger, J.K., Krausmann, F. & Eisenmenger, N., 2010. Global patterns of materials use: A socioeconomic and geophysical analysis. *Ecological Economics*, 69(5), pp.1148–1158. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800909005102 [Accessed July 13, 2014].

Steinberger, J.K. & Roberts, J.T., 2010. From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. *Ecological Economics*, 70(2), pp.425–433. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800910003733 [Accessed July 10, 2014].

Stern, D.I., 2004. The Rise and Fall of the Environmental Kuznets Curve. *World Development*, 32(8), pp.1419–1439.

Sun, J.W., 1999. The nature of CO2 emission Kuznets curve. *Energy Policy*, 27, pp.691–694.

Sun, J.W. & Meristo, T., 1999. Measurement of Dematerialization / Materialization : A Case Analysis of Energy Saving and Decarbonization in OECD Countries , 1960 – 95. *Technological Forecasting and Social Change*, 60, pp.275–294.

TCB, 2016. The Conference Board Total Economy Database. Available at: http://www.conference-board.org/data/economydatabase [Accessed January 1, 2016].

Temple, J., 2000. Inflation and growth: stories short and tall. *Journal of economic surveys*, 14(4), pp.395–426. Available at: http://onlinelibrary.wiley.com/doi/10.1111/1467-6419.00116/abstract.

Thoits, P. a & Hewitt, L.N., 2001. Volunteer work and well-being. *Journal of health and social behavior*, 42(2), pp.115–31.

Tiao, G.C. & Tsay, R.S., 1994. Some advances in non-linear and adaptive modelling in time-series. *Journal of Forecasting*, 13(2), pp.109–131. Available at: http://doi.wiley.com/10.1002/for.3980130206.

Tong, H., 1978. On a threshold model. In *Pattern Recognition and Signal Processing*. Amsterdam: Sijthoff & Noordhoff, pp. 575–586.

UN, 2012. The Future We Want. Available at: https://sustainabledevelopment.un.org/content/documents/733FutureWeWant.pdf [Accessed March 21, 2016].

UNEP, 2011a. *Decoupling natural resource use and environmental impacts from economic growth*, Paris: United Nations Environment Programme. Available at: http://www.unep.org/resourcepanel/decoupling/files/pdf/Decoupling_Report_English.pdf.

UNEP, 2011b. *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth*,

UNEP, 2009. *Global Green New Deal: An Update for the G20 Pittsburgh Summit*, Paris. Available at: https://wedocs.unep.org/rest/bitstreams/11748/retrieve.

UNEP, 2015. Global Material Flows and Resource Productivity. *United Nations Environment Programme*. Available at: https://undatacatalog.org/dataset/material-flow-dataset-0 [Accessed June 26, 2016].

UNEP, 2016. UNEP Environmental Data Explorer. *UNEP Environmental Data Explorer*. Available at: http://geodata.grid.unep.ch/webservices/ [Accessed July 12, 2016].

Vehmas, J., Luukkanen, J. & Kaivo-oja, J., 2007. Linking analyses and environmental Kuznets curves for aggregated material flows in the EU. *Journal of Cleaner Production*, 15, pp.1662–1673.

Version, D., 2011. Entrepreneurial Dynamics in Local Economic Development.

Victor, P.A., 2012. Growth, degrowth and climate change: A scenario analysis. *Ecological Economics*, 84, pp.206–212. Available at: http://dx.doi.org/10.1016/j.ecolecon.2011.04.013.

Victor, P. a., 2012. Growth, degrowth and climate change: A scenario analysis. *Ecological Economics*, 84, pp.206–212. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800911001662 [Accessed July 9, 2014].

Vinayagathasan, T., 2013. Inflation and economic growth: A dynamic panel threshold analysis for Asian economies. *Journal of Asian Economics*, 26, pp.31–41. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1049007813000341 [Accessed June 26, 2014].

Wackernagel, M., 2014. Comment on "Ecological Footprint Policy? Land Use as an Environmental Indicator." *Journal of Industrial Ecology*, 18(1), pp.20–23. Available at: http://doi.wiley.com/10.1111/jiec.12094 [Accessed June 22, 2014].

Wagner, L. a., 2002. *Materials in the Economy: Material Flows, Scarcity, and the Environment*, Denver. Available at: http://geology.cr.usgs.gov/pub/circulars/c1221/.

Wallop, H. & Butterworth, M., 2009. Recession forces a million to work part-time. *The Telegraph*. Available at: http://www.telegraph.co.uk/finance/recession/5866522/Recession-forces-a-million-to-work-part-time.html.

Wang, W. et al., 2013. Energy for Sustainable Development Decomposing the decoupling of energy-related CO 2 emissions and economic growth in Jiangsu Province. *Energy for Sustainable Development*, 17(1), pp.62–71. Available at: http://dx.doi.org/10.1016/j.esd.2012.11.007.

Ward, J.D. et al., 2016. Is Decoupling GDP Growth from Environmental Impact Possible ? *PLoS ONE*, 11(10), pp.1–14.

WCED, 1987. *Report of the World Commission on Environment and Development: Our Common Future*, Oxford.

Wei, T., 2011. What STIRPAT tells about effects of population and affluence on the environment? *Ecological Economics*, 72, pp.70–74. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800911004411 [Accessed June 28, 2014].

Wiedmann, T. et al., 2006. Allocating ecological footprints to final consumption categories with input–output analysis. *Ecological Economics*, 56(1), pp.28–48. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800905002600 [Accessed July 13, 2014].

Wiedmann, T.O. et al., 2015. The material footprint of nations. *Proceedings of the National Academy of Sciences*, 112(20), pp.6271–6276.

Wigren, R. & Wilhelmsson, M., 2007. Construction investments and economic growth in Western Europe. *Journal of Policy Modeling*, 29(3), pp.439–451.

World Bank, 2016. World Development Indicators Database. Available at: http://data.worldbank.org/news/new-country-classifications.

WTD, 2003. *Directive 2003/88/EC of the European Parliament and of the Council of 4 November 2003 concerning certain aspects of the organisation of working time*, Available at: http://eur-lex.europa.eu/legal-content/ES/TXT/PDF/?uri=CELEX:32003L0088&from=EN.

Wunder, C. & Heineck, G., 2013. Working time preferences , hours mismatch and well-being of couples : Are there spillovers ? *Labour Economics*, 24, pp.244–252.

Xinhua News Agency, 2016. *The 13th Five Year Plan*, Beijing.

York, R., 2012a. Asymmetric effects of economic growth and decline on CO2 emissions. *Nature Climate Change*, 2(11), pp.762–764.

York, R., 2012b. Asymmetric effects of economic growth and decline on CO2 emissions. *Nature Climate Change*, 2(11), pp.762–764. Available at: http://www.nature.com/doifinder/10.1038/nclimate1699.

York, R., Rosa, E.A. & Dietz, T., 2005. The Ecological Footprint Intensity of National Economies. *Journal of Industrial Ecology*, 8(4), pp.139–154.

Young, L., 2015. Reality check: Have greenhouse gas emissions decreased as the economy grows? *Global Canada*. Available at: http://globalnews.ca/news/2153522/reality-check-have-greenhouse-gas-emissions-decreased-as-the-economy-grows/.

Yu, B., Zhang, J. & Fujiwara, A., 2013. Rebound effects caused by the improvement of vehicle energy efficiency: An analysis based on a SP-off-RP survey. *Transportation Research Part D: Transport and Environment*, 24, pp.62–68. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1361920913000886 [Accessed July 20, 2014].

Zbyszewska, A., 2013. The European Union Working Time Directive: Securing minimum standards, with gendered consequences. *Women's Studies International Forum*, 39, pp.30–41. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0277539512000374 [Accessed February 10, 2015].