A Study on Job Creation in a Post-Growth Economy

Part I.

The metabolic evolution of EU-28 economic and energy performance (1995-2013): Dismantling the myth of energy intensity

Part II.

The EUROGREEN model of job creation in a post-growth economy

The Greens | EFA
in the European Parliament

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PART I: The metabolic evolution of EU-28 economic and energy performance (1995-2013): Dismantling the myth of energy intensity

Executive summary of part I

EU economies need to reduce their high levels of energy consumption without compromising the possibility to create employment. This study explores, over an average time series of 10 years, and across the EU28, the evolution of added value, energy consumption, hours worked and their related indicators (labour productivity, exosomatic metabolic rate and energy intensity). This is done both at the general economic level and at the level of the agriculture, industrial and service sectors.
Main findings:

- Because of labour productivity increases, economic stagnation is a serious threat for employment. On the other hand, because of its direct relationship with energy consumption, economic growth is a serious threat to the environment.

- It follows that the desirable outcome of job creation and a decrease in primary energy consumption has only occurred in 6 EU15 countries and in 2 new accession countries; in other cases, either employment has decreased –due to economic stagnation and the crisis- or energy consumption –particularly prior to 2008- has increased.

- Energy Intensity has generally been improving, with less energy required to generate one unit of added value. However, this is a misguiding indicator that does not consider the total amount of energy consumed and therefore does not tell how much energy an economy consumes , that is, how fast is its metabolic profile.

- Moreover, because employment has shifted away from energy intensive sectors (agriculture and industry) and towards the service sector, energy-related indicators have tended to improve. However, although EU countries rely less on productive sectors, they rely more on international trade: while the productive economy might appear to be on a path of increased sustainability, import-dependent consumption is not. Therefore, a bias in energy figures arises. When the structural bias is accounted for, employment increases associated to decreases in primary energy consumption are associated to only 4 countries in EU15 and 2 in new accession countries.

- Policies for job creation in a post-growth sustainable society need to be thought, such as work sharing or the relocation of the industrial sector.

Glossary to part I

Exosomatic Metabolic Rate (EMR) The amount of energy consumed in a determined compartment of society per unit of time. In the present study it refers to the amount of energy consumed in economic sectors –and its subsectors- per hour of paid work. If the endosomatic metabolic rate refers to the amount of energy consumed by a human body (i.e. 9.6 MJ per day, or 0.4 MJ per hour), that is, it refers to the biological metabolism, the exosomatic rate refers to societal metabolism, that is, it accounts for the energy consumed by machines and other tools used by human activity.

Economic Labour Productivity (ELP) Labour Productivity. In sociometabolic studies it is necessary to specify the reference to the monetary (economic) domain, and to distinguish it from the biophysical. For instance, the labour productivity of a farmer can refer to the calories of food that are produced per hour of farmer's work.

Energy Intensity (EI) It is the amount of energy required to produce one unit of economic output, and it is normally expressed in MJ/€. Because labour productivity and the exosomatic metabolic rate are different for different economic sectors, EI varies a lot between them. Decreases in EI are desirable since they support the idea of decoupling economic growth from energy consumption. At societal level these can be achieved either by improving energy efficiency and saving, or by moving employment away from energy intensive sectors, notably agriculture and industry. The latter strategy, however, does not guarantee that a society can do without the consumption of energy intensive products as often, trade liberalization allows for the displacement of energy intensive production to other countries.

Social Metabolism A metaphor used to consider that society behaves like a biological metabolism which in order to maintain and reproduce itself requires a constant throughput of materials and energy. Adopting the perspective of social metabolism is useful in order to understand the biophysical impact of a society and its economy. It can be represented by monetary dimensions (i.e. added value, per capita income, etc.) but also by biophysical (energy consumption, land use, hours employed). Unlike biological metabolism which depends on biomass, social metabolism can depend also from non-renewable energy and materials. It is therefore of paramount importance to monitor it and adopt adequate methodologies to do it.

Agriculture sector. It considers data related to agriculture, forestry and fishing activities of Eurostat database.

Industrial sector. It considers data related to energy and mining, building and manufacturing activities of Eurostat database.

Service sector. It considers data related to service and government, to freight and passenger commercial transport and other residual activities of Eurostat database.

1. Metabolic performance at aggregate level

1.1. Introduction

This study offers an analysis of the metabolic and economic performance of the EU28 at aggregate and sectorial level (agriculture, industry and services), over time. It studies two main indicators: energy consumption and added value, in relation to employment, expressed in terms of hours worked. Also, considering shifts in the labour force composition across sectors (outsourcing of manufacturing activities), it studies the effects of the metabolic and economic performance had these shifted not occurred. Particularly interesting is the case of how improvements in energy intensity are biased due to this structural adjustment of EU economies.

1.2. Time span of available time series

There are mainly two time series, one between 1995-96 and 2008 (Belgium, Denmark Germany, Italy, Sweden, UK Cyprus and Croatia)[1], the other between 2000 and 2012-13 (Austria, Ireland, Greece, Spain, Finland, Luxembourg, Portugal, Bulgaria, Cyprus, Czech Republic, Estonia, Latvia, Malta, Poland, Romania, Slovenia, Slovakia). France and Hungary have shorter ones (2003-2012 and 2008-2012); Lithuania and The Netherlands longer ones (1997-2012 and 1998-2012). Because 2008 is the year when the crisis started, the comparative results can be slightly biased between countries whose data belong to different time series; moreover the performance of Hungary is affected by a data series that belongs only to the post-crisis period. For this reason, results presented with these time series are compared with the results obtained from adopting one uniform pre-crisis time series (2000-2008) for all EU countries except Hungary.

[1] Time series for Germany and Italy would be available until 2012, but incoherencies between data sources of work time, made us chose to limit the study to 2008. For a detailed description, see Appendix 2.

Table 1. Available time series for the study. For Germany and Italy, Eurostat worktime series (2010-2013) excluded because not coherent with ILO worktime series. For Hungary, very short time series, beginning after the crisis.

1.3. Metabolic evolution of EU28

Table 2 is a summary of the per year change in hours, added value and primary energy consumption for each sector of the EU28 economies. Countries in grey are those for which the time series ends in year 2008.

	Per year change													
	HOURS	AGR	IND	SER	**GDP**	AGR	IND	SER	**ENER**	AGR	IND	SER	**EMR**	**ELP**
at	**0,2%**	-2,8%	-0,3%	0,8%	**1,5%**	0,0%	0,7%	1,9%	**1,6%**	0,6%	1,8%	1,4%	1,4%	1,3%
be	**1,2%**	-1,9%	0,2%	1,6%	**2,3%**	-2,4%	0,9%	2,8%	**0,9%**	-1,7%	0,0%	2,0%	-0,2%	1,1%
dk	**0,6%**	-2,8%	-0,8%	1,2%	**1,9%**	-7,6%	2,0%	2,1%	**0,0%**	-1,3%	-0,9%	0,9%	-0,6%	1,3%
de	**0,6%**	-1,9%	-0,8%	1,4%	**1,5%**	0,3%	0,8%	1,9%	**0,2%**	-100,0%	0,2%	0,4%	-0,5%	0,9%
ie	**0,1%**	-3,6%	-3,4%	1,8%	**3,0%**	-3,9%	0,7%	4,3%	**-0,6%**	-2,1%	-1,1%	-0,1%	-0,7%	2,9%
el	**-0,8%**	-2,9%	-2,9%	0,2%	**-0,1%**	-4,2%	-2,2%	0,7%	**-1,3%**	-10,0%	-3,2%	0,9%	-0,5%	0,7%
es	**0,3%**	-2,5%	-3,1%	1,8%	**1,3%**	-1,6%	-1,0%	2,4%	**-0,2%**	0,8%	-1,5%	0,9%	-0,5%	1,0%
fi	**0,4%**	-2,4%	-0,7%	1,1%	**1,4%**	-0,4%	-1,0%	2,7%	**0,0%**	0,3%	-1,0%	1,6%	-0,4%	1,0%
fr	**0,4%**	-2,3%	-0,6%	0,9%	**1,1%**	-0,2%	-0,2%	1,5%	**-1,3%**	0,7%	-3,0%	-0,3%	-1,7%	0,7%
it	**0,1%**	-3,2%	-0,7%	0,9%	**1,3%**	-2,2%	0,5%	1,8%	**1,1%**	-0,4%	0,1%	2,1%	1,0%	1,2%
lu	**2,5%**	-2,8%	0,8%	3,0%	**2,5%**	-4,0%	-0,9%	3,2%	**1,0%**	2,6%	-0,9%	1,8%	-1,4%	0,1%
nl	**1,0%**	0,4%	-1,3%	1,7%	**1,7%**	-1,7%	0,7%	2,1%	**-0,2%**	-1,2%	-0,8%	0,7%	-1,1%	0,7%
pt	**-0,7%**	-3,3%	-3,5%	1,0%	**0,5%**	-4,3%	-1,6%	1,4%	**-0,5%**	-4,7%	-1,5%	1,0%	0,2%	1,2%
se	**0,9%**	-1,9%	-0,3%	1,5%	**3,0%**	-1,3%	2,5%	3,4%	**-0,6%**	-1,2%	-0,9%	-0,2%	-1,6%	2,1%
uk	**0,8%**	-1,8%	-1,1%	1,6%	**2,7%**	-3,1%	0,4%	3,6%	**-0,1%**	-2,9%	-1,0%	0,6%	-0,9%	1,8%
bg	**0,5%**	-1,2%	-0,1%	1,5%	**3,7%**	-3,5%	4,9%	4,2%	**-0,7%**	-3,7%	-3,5%	3,7%	-1,2%	3,2%
cy	**3,5%**	3,1%	2,8%	3,8%	**3,5%**	-2,9%	3,8%	3,7%	**1,3%**	20,6%	-4,1%	3,4%	-2,2%	0,0%
cz	**-0,2%**	-3,0%	-0,6%	0,3%	**2,6%**	0,4%	2,6%	2,7%	**-1,0%**	-1,1%	-2,4%	0,9%	-0,8%	2,8%
ee	**-0,3%**	-4,3%	-0,7%	0,3%	**3,6%**	1,9%	3,9%	3,6%	**1,9%**	5,5%	0,0%	2,9%	2,2%	3,9%
hr	**0,1%**	-3,3%	0,5%	1,0%	**3,8%**	0,9%	2,9%	4,4%	**3,4%**	2,8%	2,4%	4,5%	3,3%	3,7%
lv	**-1,8%**	-5,9%	-2,2%	-0,9%	**4,0%**	1,2%	3,1%	4,4%	**2,6%**	1,1%	3,1%	2,6%	4,5%	5,8%
lt	**0,3%**	-6,2%	5,3%	0,5%	**4,4%**	-1,5%	4,4%	5,2%	**0,4%**	-3,0%	0,0%	1,0%	0,1%	4,2%
hu	**-1,7%**	-0,5%	-2,7%	-1,3%	**-2,0%**	1,9%	-1,9%	-2,2%	**-4,6%**	-6,7%	6,5%	3,5%	-3,0%	-0,3%
mt	**1,4%**	1,8%	-2,0%	2,5%	**2,1%**	-1,3%	-2,3%	3,6%	**2,5%**	1,9%	0,6%	2,7%	1,1%	0,7%
pl	**1,0%**	-2,7%	0,9%	2,3%	**3,8%**	2,5%	4,1%	3,7%	**0,7%**	-1,9%	-2,0%	4,5%	-0,4%	2,7%
ro	**-2,0%**	-5,8%	-1,5%	1,3%	**3,5%**	-3,3%	4,4%	4,0%	**-0,2%**	1,9%	-2,6%	4,1%	1,8%	5,6%
si	**-0,2%**	-3,9%	-1,5%	1,6%	**1,7%**	-2,0%	1,1%	2,2%	**0,0%**	-0,8%	-1,3%	1,2%	0,2%	1,9%
sk	**0,6%**	-4,7%	0,2%	1,2%	**4,6%**	2,7%	4,4%	4,9%	**-0,6%**	-3,0%	-0,4%	-0,9%	-1,2%	4,0%

Table 2. Per-year changes in employment, GDP and primary energy consumption.

Notes. Between 2004 and 2005 probably a change in accounting of energy in Cyprus

Between 2011 and 2012 collapse of energy in Greek agriculture

Accounting of energy in agriculture disappears in Germany

Anomaly in energy account for 2012 in Hungary

Between 2001 and 2002 a -30% collapse of employment in Romanian agriculture

1.4. GDP growth and job creation

GDP has grown in all countries except Greece and Hungary (in this case because the time series starts only in 2008, when the crisis hit). Hours worked have increased in all countries except Greece, Portugal, Czech Republic, Latvia Hungary Romania and Slovenia. They have always increased less than GDP, except in Hungary and Cyprus. This implies that labour productivity (ELP) has increased in almost all countries.

Cyprus is a relevant case, with the highest growth rate in employment –followed by Luxembourg-, and one of the highest growth rates in GDP (table 2). However, Cyprus time series ends in 2008: its GDP in 2014 was down at the levels of 2005, but we have no information on hours worked. Romania, on the other hand, has rapidly grown in GDP, but with the most significant loss in employment[2].

Figure 1a below shows per year changes in labour productivity and employment. It can be seen that Ireland and new accession countries have experienced the highest increases in labour productivity (up to almost 6% per year in Latvia and Romania). Employment, however, has not followed a similar path and in several cases has decreased or remained stable, with increases of less than 0.5% per year. To avoid the bias due to different time series, the same graph for the same time series 2000-08 is produced (Figure 1b). Prior to the crisis, employment grew in all countries except Romania and labour productivity in all countries except Cyprus. This, from a growth perspective, was a desirable outcome since GDP increased largely for the combined effect of job creation and increased productivity.

[2] It is to be noted that between 2001 and 2002 employment in agriculture collapsed from 8.2 billion hours to 5.9, but with only a minor fall in its added value and energy consumption.

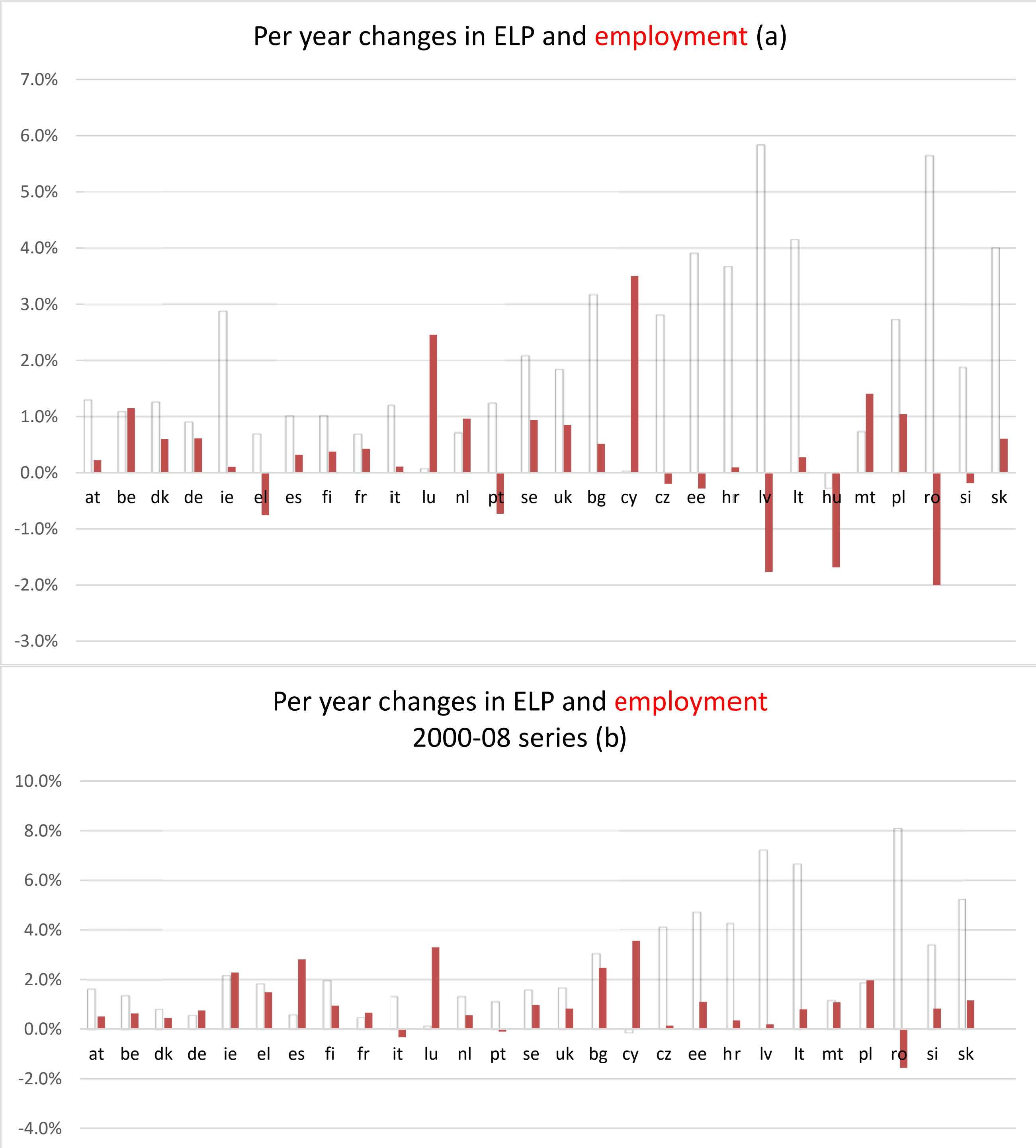


Figure 1a and 1b. Per-year changes in ELP (empty bars) and employment (solid bars).

Particularly interesting is the plotting of labour productivity and job creation as in figure 1c (EU15) and 1d (new accession countries). While labour productivity has increased in all cases except Cyprus and Hungary (which appear in the left hand-side quadrants of the graph), employment has not, with several countries that have lost jobs (bottom quadrants of the graph).

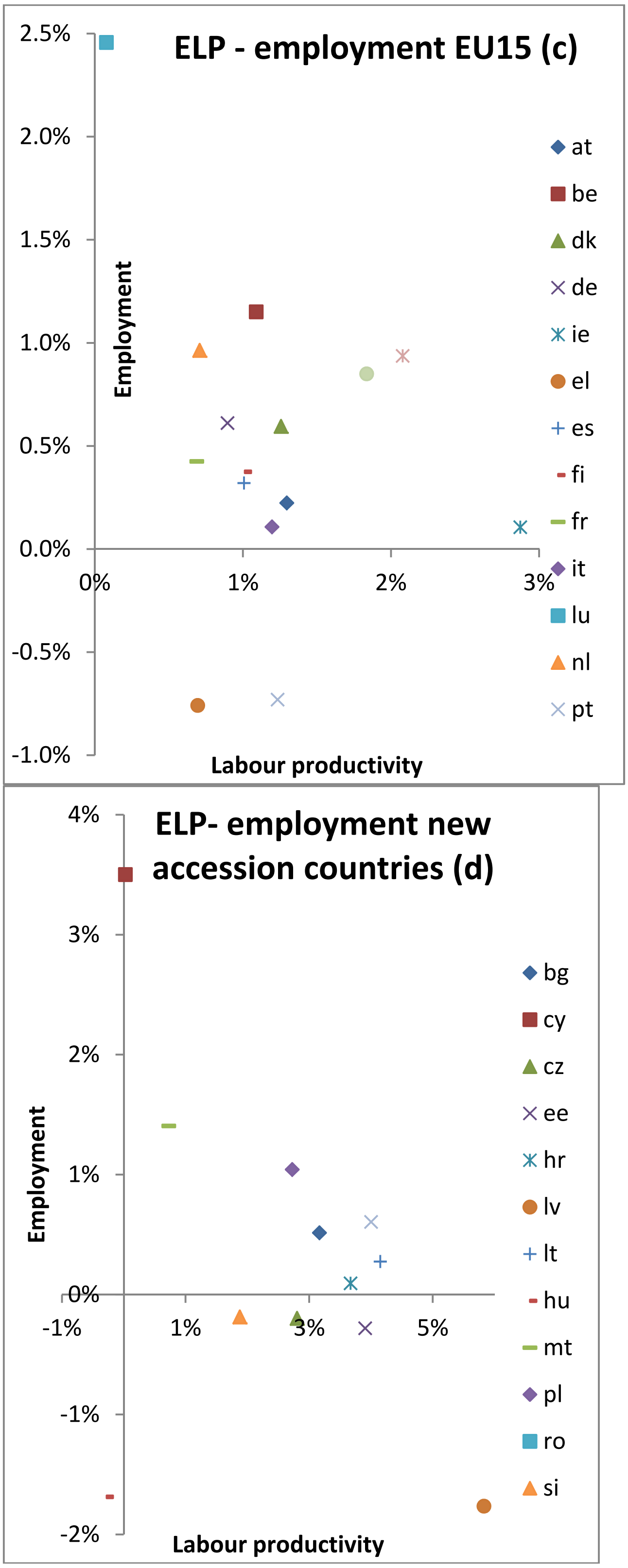


Figure 1c and 1d. Per-year changes in ELP (x-axis) and employment (y-axis) EU15 and new accession countries.

1.5. Energy consumption

Notwithstanding relocation and restructuring over the period covered (which will be dealt with in section 2), primary energy consumption shows irregular trends. While in some cases this has increased, in others it has decreased. Figure 2a below relates changes in primary energy consumption with the evolution of the exosomatic metabolic rate (EMR), that is, the energy consumed per hour of work.

A decrease in the EMR is desirable since it represents a decrease in the energy consumed per hour of work. Unfortunately, there are ten countries in which this has not occurred (Austria, Italy, Portugal, Estonia, Croatia, Latvia, Lithuania, Malta, Romania and Slovenia). For those where it has occurred, a decrease in EMR can open the way to a decoupling between job creation (and added value) and energy consumption. However, if jobs (and added value) are created at a faster rate than the decrease in EMR, total energy consumed will still increase. This is the case for other six EU countries in which improvements in EMR have not been sufficient to counterbalance the increase in hours worked, therefore resulting in a higher consumption of primary energy (Belgium, Denmark, Germany, Luxembourg, Cyprus and Poland).Finally, half of the EU countries have increased their energy consumption throughout the different time series.

When time series are unified to the 2000-08 trend (Figure 2b), the picture is even more bleak. EMR increased in 11 countries (the same as before plus Greece). And all of EU28 countries except only four (France, Sweden, UK and Czech Republic) have increased their primary energy consumption. From a sustainability perspective, the high growth rates prior to the crisis were not a good new.

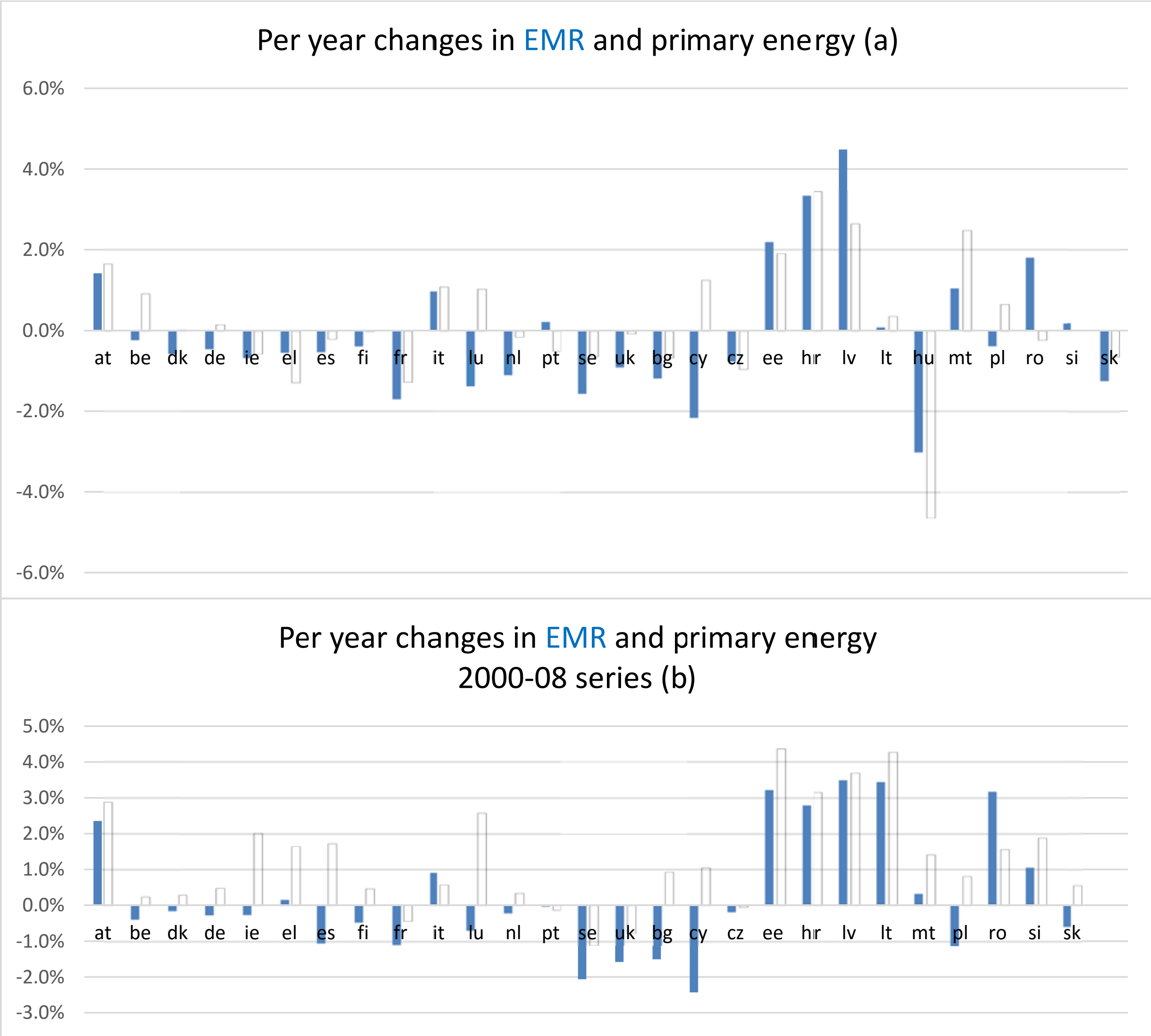


Figure 2a and 2b. Per-year changes in EMR (solid bars) and primary energy consumption (empty bars).

Representing the EMR vs. Primary Energy consumption relationship in a dispersion graph helps in better understanding the situation. For the complete time series (that is, including some time series that extend into the crisis), figure 2c (EU15) and 2d (new accession countries) show that the top-right quadrant is the less desirable situation (both EMR and primary energy consumption increase). The bottom-right quadrant is also non desirable, because, although the EMR improves, primary energy consumption is still increasing. This could be the case of an economy in which job creation outnumbers the effect of improved energy efficiency: although less energy is consumed per hour of work, increased employment and hours worked counter balance any energy efficiency improvement. The top-left quadrant shows where primary energy consumption has decreased (which is desirable) but energy consumption per hour worked has not. Although desirable from an energy saving perspective, the only way total energy consumption can decrease when energy consumption per hour has increased is because less hours have been worked. This is the case for Portugal, Slovenia and Romania. The only desirable outcome is to appear in one part of the bottom-left quadrant of the graph. Although this is the case for seven EU15 countries, only four in the new accession group performed in this way. The bottom-left quadrant implies a desirable situation, but it is still not related to employment: a decrease in primary energy consumption might not necessarily be due only to an improvement in energy efficiency. Increased unemployment can also play a role. To this extent, only when the decrease in EMR is larger than the decrease in primary energy consumption, we can infer that jobs are created.

In detail, the relation between changes in employment (job creation), in energy consumption and in their metabolic rate is the following:

$$\Delta \text{ hours worked (\%)} = \Delta \text{ primary energy (\%)} - \Delta \text{ EMR (\%)} \qquad (1)$$

That is, the condition for job creation is this:

$$\Delta \text{ primary energy (\%)} > \Delta \text{ EMR (\%)} \qquad (2)$$

That is, the space only to the left of the diagonal line that cuts across figure 2 represents the condition for job creation. After this condition is imposed, only six EU15 countries (France, Sweden, UK, Ireland, The Netherlands and Spain) and two new accession countries(Bulgaria and Slovakia) have managed to increase employment while decreasing energy consumption.

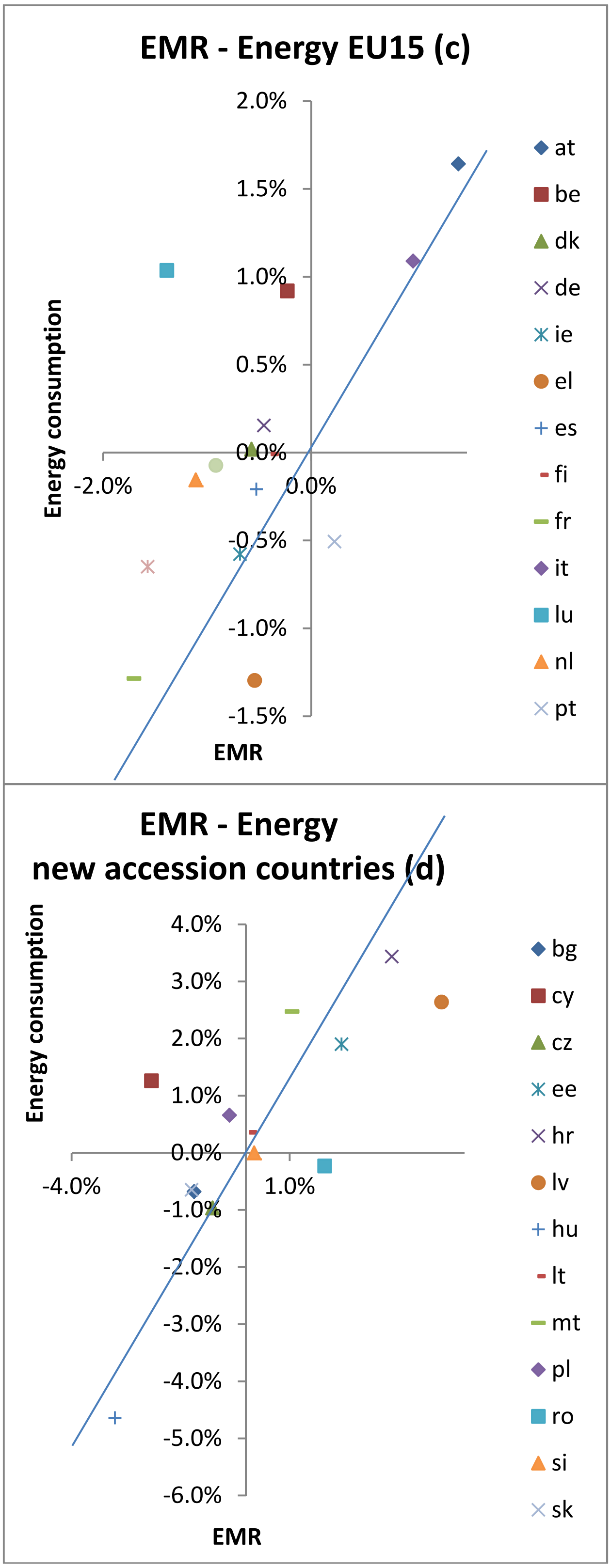


Figure 2c and 2d. Per-year changes in EMR (x-axis) and primary energy consumption (y-axis) EU15 and new accession countries.

1.6. Energy intensity

Energy intensity is an indicator that combines energy consumption with economic productivity and is normally expressed in MJ/€. The figure below shows that energy intensity has improved in almost all EU countries, independently if we compare across the different time series, or using the same 2000-08 series for all countries.

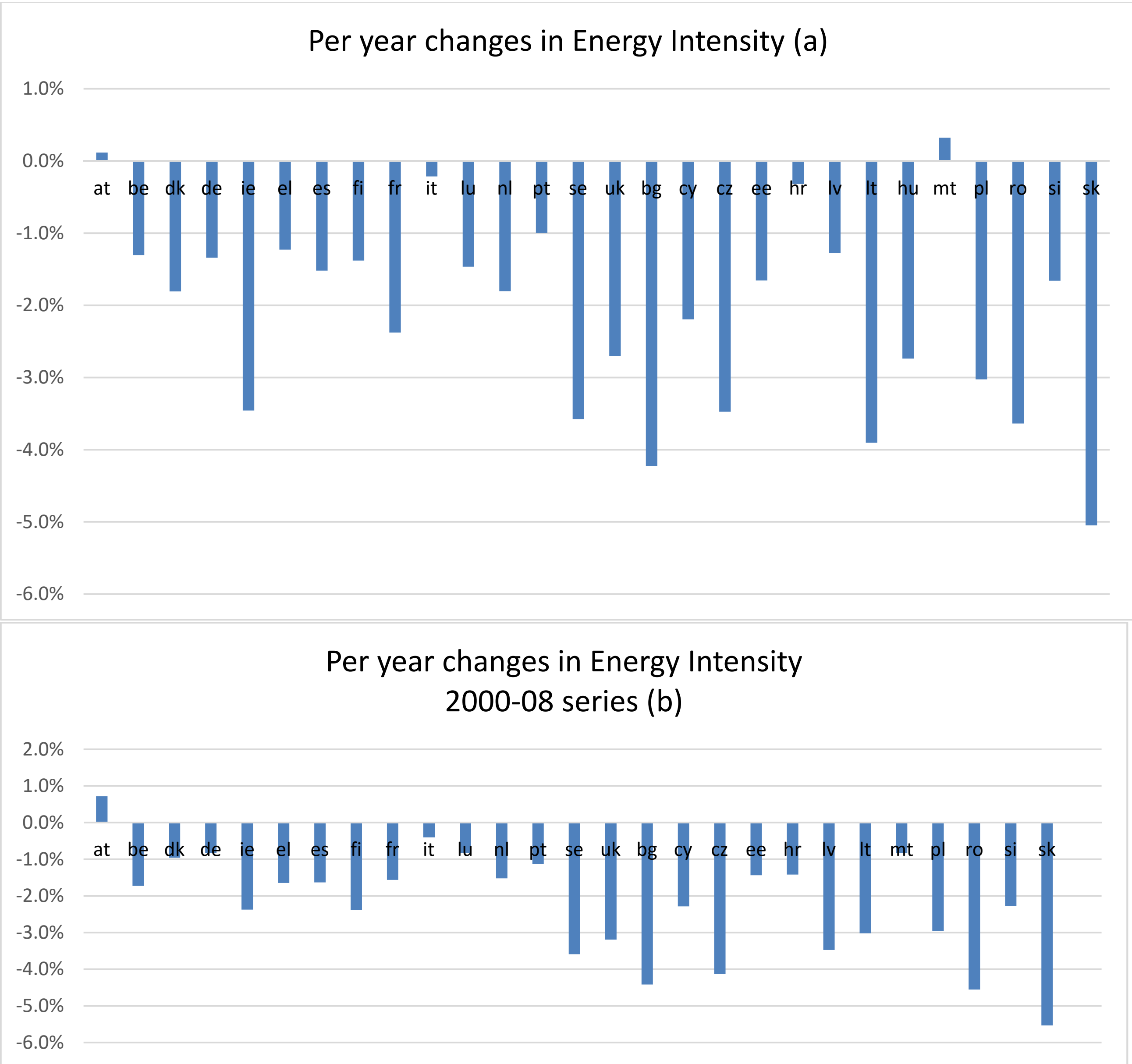


Figure 3a and 3b. Per-year changes in energy intensity.

An improvement in EI is apparently good news, since it indicates that the evolution of the EU economies goes on a path of decoupling between GDP creation and energy consumption. EI improvement is the rationale for insisting on economic growth: production will become more efficient, resources and energy will be saved and well-being maintained. However, as we have seen already, there are two limitations to the apparently good news that we can see in terms of better Energy Intensity.

1. The first refers to job creation: from figure 1 we can see that the increase in GDP –which contributes to a better energy intensity- is mainly due to an increase in labour productivity, and not always reflected by an increase in employment. Automation can be one of the reasons that allow for higher labour productivity: increased economic output, with relative decoupling of energy consumption, but not necessarily related to an increase in employment. In line with equations (1) and (2) we can define the relationship between job creation, GDP and labour productivity this way:

$$\Delta \text{ hours worked } (\%) = \Delta \text{ GDP } (\%) - \Delta \text{ ELP } (\%) \quad (3)$$

That is, the condition for job creation is this:

$$\Delta \text{ GDP } (\%) > \Delta \text{ ELP } (\%) \quad (4)$$

2. The second limitation is due to the lack of an absolute decrease in energy consumption. From figure 2 we see that primary energy consumption has been increasing in half of the EU countries, while in the other half it has decreased only slightly. The exceptions are Greece, the country most hardly hit by the crisis (-1.3% per year) and Hungary, whose time series only starts in 2008 (-4.6%). From the perspective of limited natural resources, the absolute amount of primary energy consumed matters more than the Euros generated by this consumption.

Moreover, there is another important issue that limits the validity of the Energy Intensity indicator: when applied over a time series, it refers to non-equivalent domains. EU economies in the late 1990s had larger industrial and agricultural sectors than today. These sectors are notoriously characterized by high energy intensities; on the other hand, the service sector performs energetically better. This shift in the sectorial composition of almost all EU economies, in which labour force has mainly shifted from the industrial to the service sector is an important reason for the improvements in energy efficiency. However, the EU economies are still dependent on agricultural and industrial products which, instead of being produced internally, are being increasingly imported from elsewhere. The environmental load of energy intensive sectors is thus exported to other countries, notably China. The net emission transfer of developed Annex B countries to non Annex-B countries[3] has increased exponentially in a couple of decades, as figure 4 shows (Peters et al. 2011).

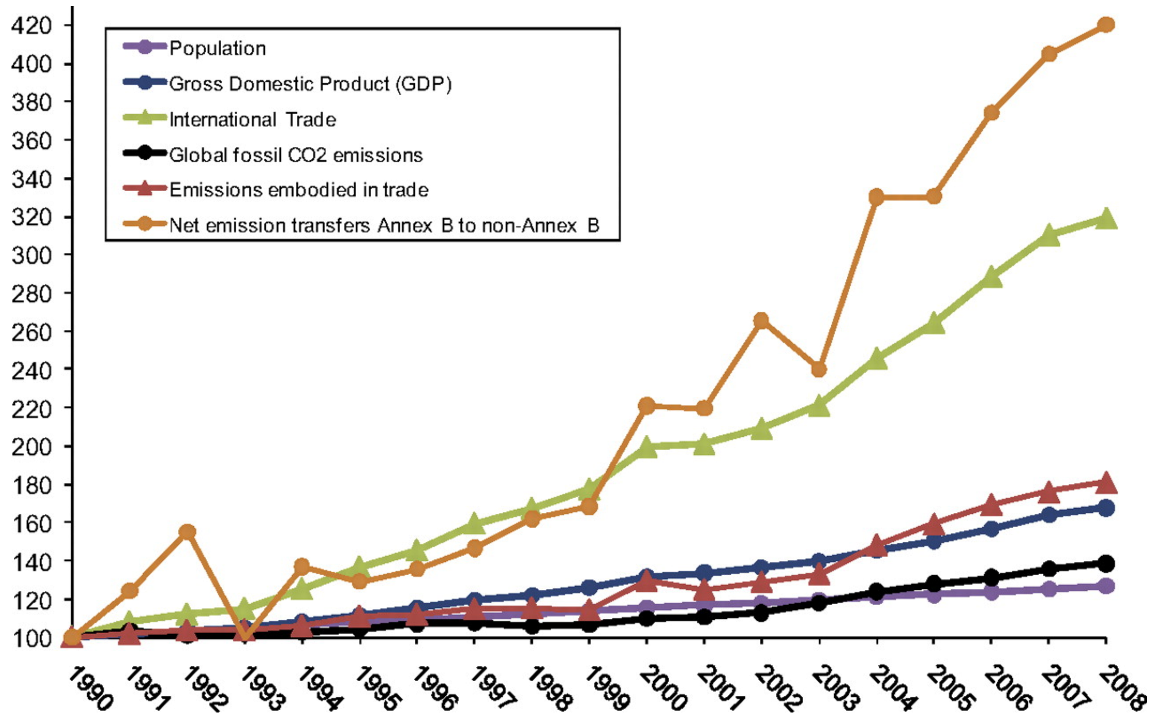


Figure 4. The development of various global macro variables indexed to 1990. Source: Peters et al. 2011.

In this study the emissions associated to the production of goods traded are calculated. Accordingly, these have globally increased at a rate of +3.4% per year from 4.3 Gt CO2 in 1990 (20% of global emissions) to 7.8 Gt CO2 in 2008 (26%). Focusing on products and services traded from developing to developed countries the net emission transfers increased at a rate of +8% per year from 0.4 Gt CO2 in 1990 to 1.6 Gt CO2 in 2008. Trade-related emissions between developing and developed countries have increased

[3] According to the Kyoto Protocol, Annex B countries are developed countries that are committed to a reduction in CO2 emissions, while non-Annex B countries are developing countries with no CO2 reduction commitments.

yearly at a rate larger than any other decrease in a country's primary energy consumption. This implies that although the economic sectors of EU economies tend to consume less energy, the population of these countries is increasing its material consumption because of the large increase in imports of products and services. The CO2 emissions associated to these imports constituted in 1990 less than 10% of the trade-related emissions of global trade. In 2008 this share grew to more than 20%. Peters et al. (2011) claim that international trade is a significant factor in explaining the change in emissions in many countries, from both a production and consumption perspective and propose to monitor, along emissions and energy consumption related to the EU28 territory, also emission transfers from overseas trade.

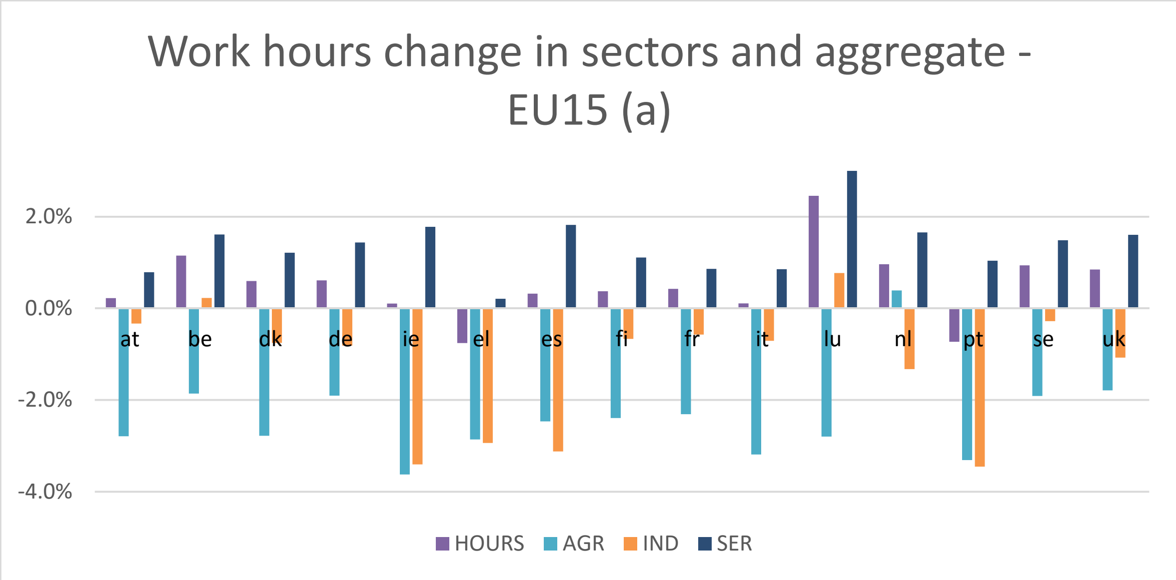
UNEP (2016, p.16) claims that "material efficiency mitigated some of the growth of material use driven by growing population and world economy between 1970 and 1990. Since 1990, there has not been much improvement in global material efficiency, which actually started to decline around 2000. Globally, more material per unit of GDP is now required. Production has shifted from very material-efficient countries to countries that have low material efficiency, resulting in an overall decline in material efficiency". In this way, if material extraction, energy use or CO2 emissions related to traded goods were to be properly accounted, the energy metabolism of importing countries would be significantly higher.

2. Metabolic performance at sectorial level

2.1. Sectorial analysis

Employment in agriculture has almost always decreased: from table 1 we can see that this is the case except for Cyprus, the Netherlands and Malta. Also, except for Belgium, Luxembourg, Cyprus, Croatia, Latvia, Poland and Slovakia, employment in productive sectors has always decreased. Finally, except Hungary -for which the time series starts only in 2008- employment in the service sector has always increased. EU countries rely less on productive sectors and more on international trade. Their material economies have shifted from being productive to being characterized by high levels of consumption.

Figure 5a and 5b below shows the trend in total employment and the relative change in the composition of the labour force between the three main sectors, per year and from the beginning to the end of each country's time series.


Work hours change in sectors and aggregate - EU15 (a)
2.0%
0.0%
-2.0%
-4.0%
at
be
dk
de
ie
el
es
fi
fr
it
lu
nl
pt
se
uk
HOURS
AGR
IND
SER

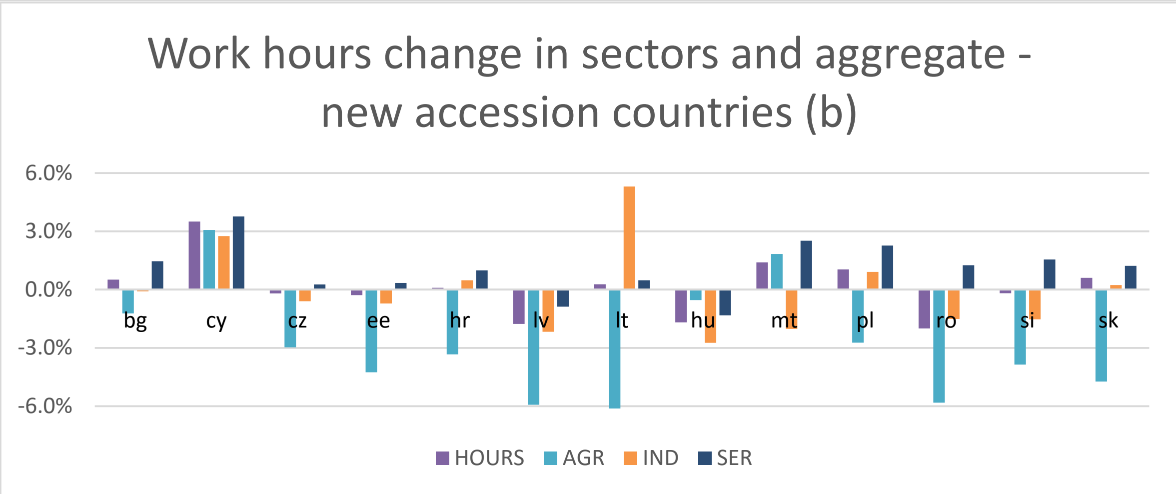
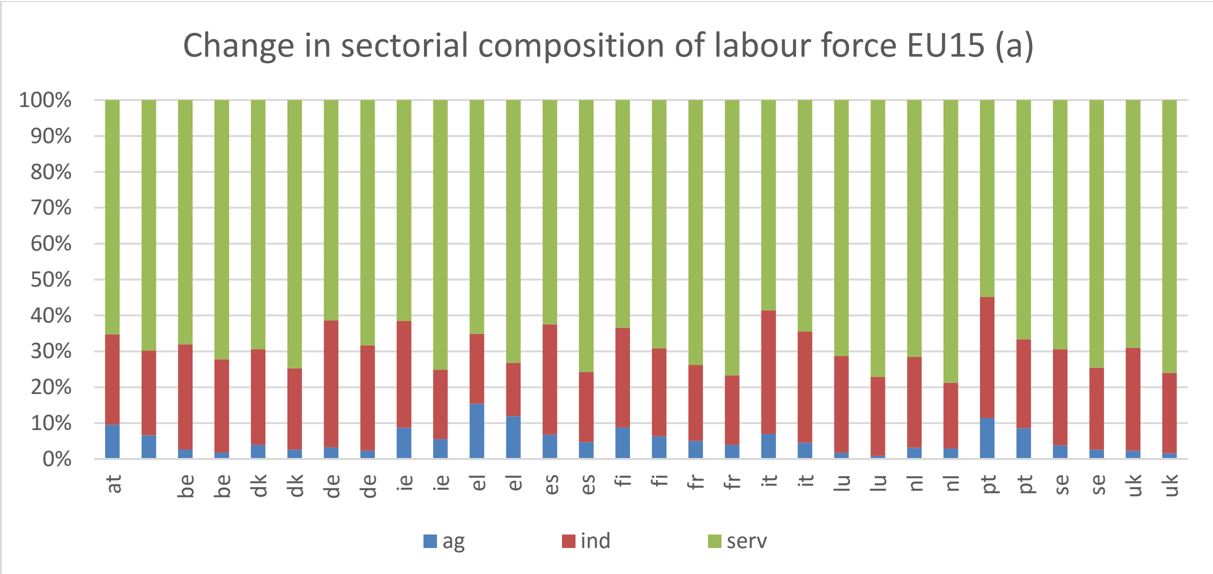

Work hours change in sectors and aggregate - new accession countries (b)
6.0%
3.0%
0.0%
-3.0%
-6.0%
bg
cy
cz
ee
hr
lv
lt
hu
mt
pl
ro
si
sk
HOURS
AGR
IND
SER

Figure 6a and 6b shows instead the relative composition at the beginning and at the end of each country's time series.



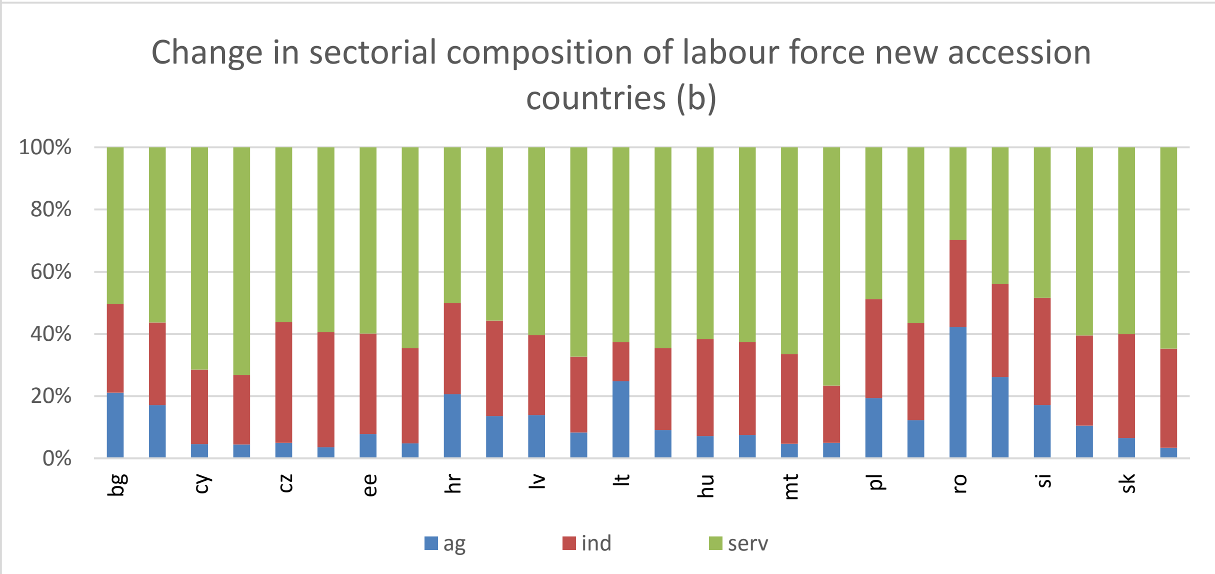


Figure 6a and 6b. Per-year change in worked hours: aggregate, agriculture, industry and service and government for the EU countries.5c and 5d: change in sectorial composition of labour force from beginning to end of each country's time series.

The values of figure 6a and 6b are also visible in table 3 below.

	ag	ind	serv		ag	ind	serv
at	10%	25%	65%	bg	*21%*	29%	*50%*
	7%	24%	**70%**		**17%**	27%	56%
be	3%	29%	68%	cy	5%	24%	***71%***
	2%	26%	**72%**		**4%**	22%	**73%**
dk	4%	27%	69%	cz	5%	39%	*56%*
	3%	23%	**75%**		**4%**	37%	59%
de	3%	35%	61%	ee	8%	32%	60%
	2%	29%	68%		5%	31%	65%
ie	9%	30%	62%	hr	*21%*	29%	*50%*
	6%	19%	**75%**		14%	31%	56%
el	15%	19%	65%	lv	14%	26%	60%
	12%	15%	**73%**		8%	24%	67%
es	7%	31%	62%	lt	*25%*	13%	63%
	5%	20%	**76%**		9%	26%	65%
fi	9%	28%	63%	hu	7%	31%	61%
	6%	25%	69%		7%	29%	62%
fr	5%	21%	***74%***	mt	5%	29%	66%
	4%	19%	**77%**		5%	18%	**77%**
it	7%	34%	*59%*	pl	*19%*	32%	***49%***
	5%	31%	64%		12%	31%	56%
lu	***2%***	26%	70%	ro	*42%*	28%	***30%***
	1%	21%	**75%**		**26%**	30%	**44%**
nl	3%	25%	***72%***	si	*17%*	34%	***48%***
	3%	18%	**79%**		11%	29%	61%
pt	11%	34%	*55%*	sk	7%	33%	60%
	9%	25%	67%		**3%**	32%	65%
se	4%	27%	69%				
	3%	23%	**75%**				
uk	***2%***	29%	69%				
	2%	22%	**76%**				

Table 3. Composition of labour force, at the beginning and end of each time series. Values underlined and in red are associated to high % agriculture or low % service sector. Values in bold are associated to low % agriculture or high % service.

At the beginning of the series, in EU15 the service sector employed between 55% (Portugal) and 74% (France) of the workforce. At the end, between a minimum of 64% (Italy) and a maximum of 79% (The Netherlands). In new accession countries, the relative composition has increased from between a minimum of 30% (Romania) and a maximum of 71% (Cyprus) to a range between 44% (Romania) and 77% (Malta).

If we look only at the relative changes of hours worked in each sector, and along the different time series, we observe that agriculture has increased its weight only in Hungary and Malta; industry only in Croatia and Romania. On the other hand the service sector has increased its relative weight in each one of the EU countries.

2.2. Thought experiment: unbiased EMR and ELP

The relocation and restructuring of the economic sectors allows us to consider what would have been the evolution of labour productivity, exosomatic metabolic rate and energy intensity if changes in labour force composition had not occurred. The rationale for this thought experiment is due to the fact that the EU economies have not consumed less, but simply shifted consumption from goods produced internally towards an increased relevance of goods imported. The test has been run in the following way:
for each EU country, energy consumption and GDP are modelled multiplying, for each sector, the EMR and ELP corresponding to the last year of the series with the percentage of the labour force corresponding to the first year of the series. That is, total worked hours are maintained as well as the EMR and ELP of each sector. However, these hours are allocated to each sector based on the proportions at the start of the series. This is done in order to eliminate the bias, in the aggregate EMR, ELP and EI that results from a shift from energy intensive jobs towards less energy intensive ones (as well as more economically productive). That is, improvements in energy efficiency and labour productivity are due only in part to improvements, at the sectorial level, in energetic and economic performance.
Figure 7 below shows how, at the aggregate level, the EMR has changed. Except Bulgaria, Croatia, Lithuania, Romania and Slovenia, the EMR would have always been higher then now if relocation and restructuring of the economic sectors and the consequent changes in labour force composition had not occurred.

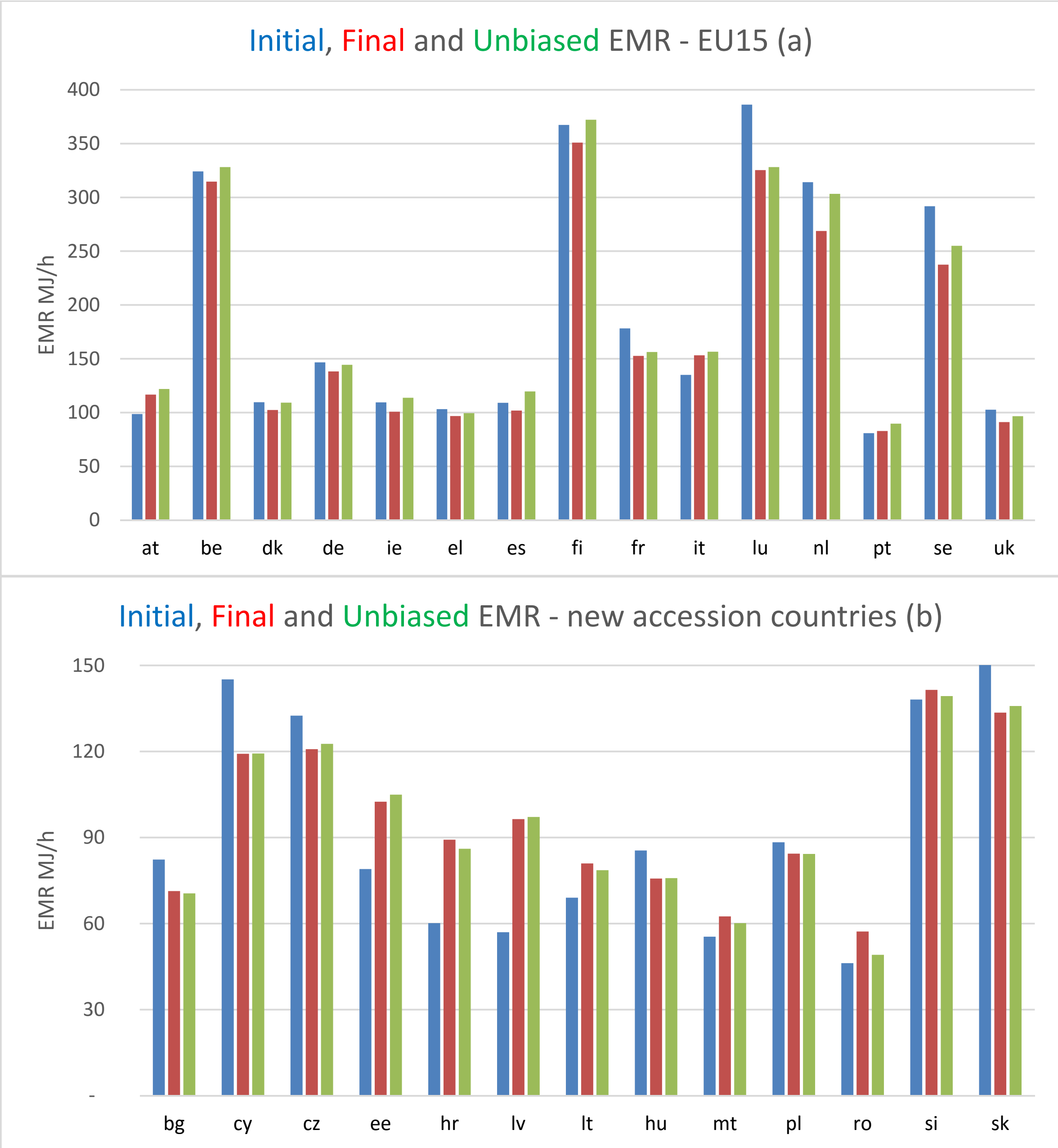
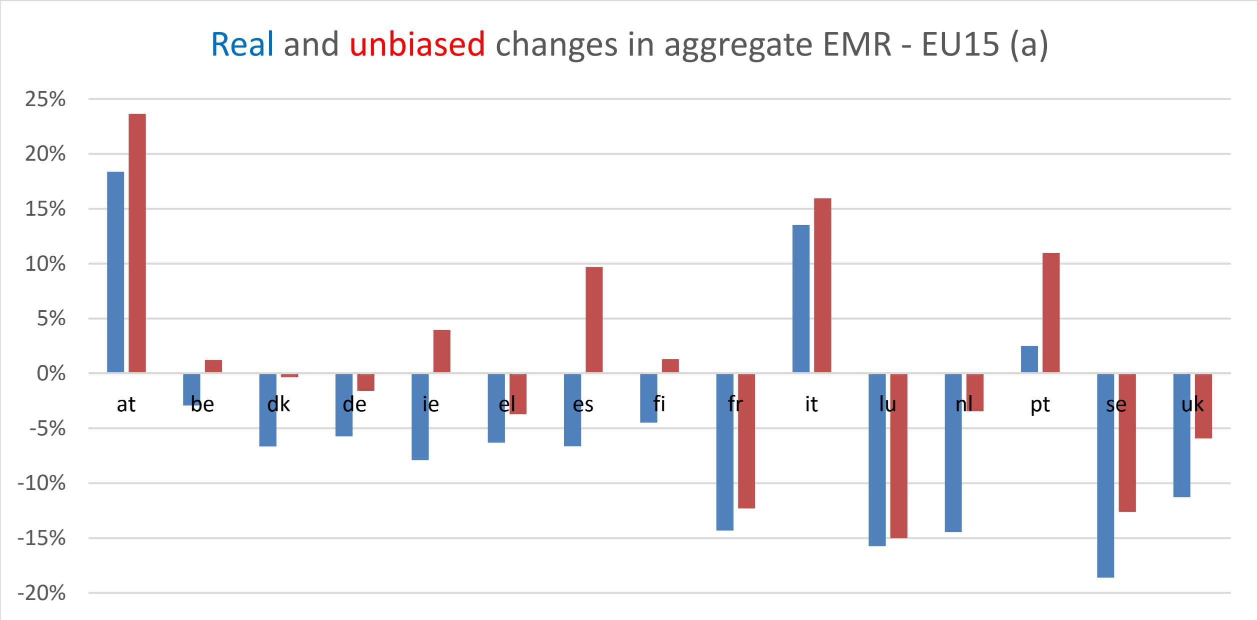


Figure 7a and 7b. EMR aggregate values, at beginning and end of each individual series and unbiased EMR assuming no sectorial shift of labour force.

Another important feature we observe from figure 7 is how some EU countries, particularly in north EU, are highly energy intensive. No matter the evolution over time, Belgium, Finland, Luxembourg, The Netherlands and Sweden have very high metabolic profiles well above 250 MJ/h; they are followed by France, Italy and Germany. Eastern European countries, on the other hand, have lower metabolic profiles, with only Slovenia, Slovakia, Cyprus and Czech Republic consuming primary energy at a rate above 100 MJ/h; Estonia, Croatia and Latvia on the other hand are severely increasing and approaching the rate of 100 MJ/h.

In more detail, the real and unbiased change in EMR with respect to the base year are reproduced in the figure below.



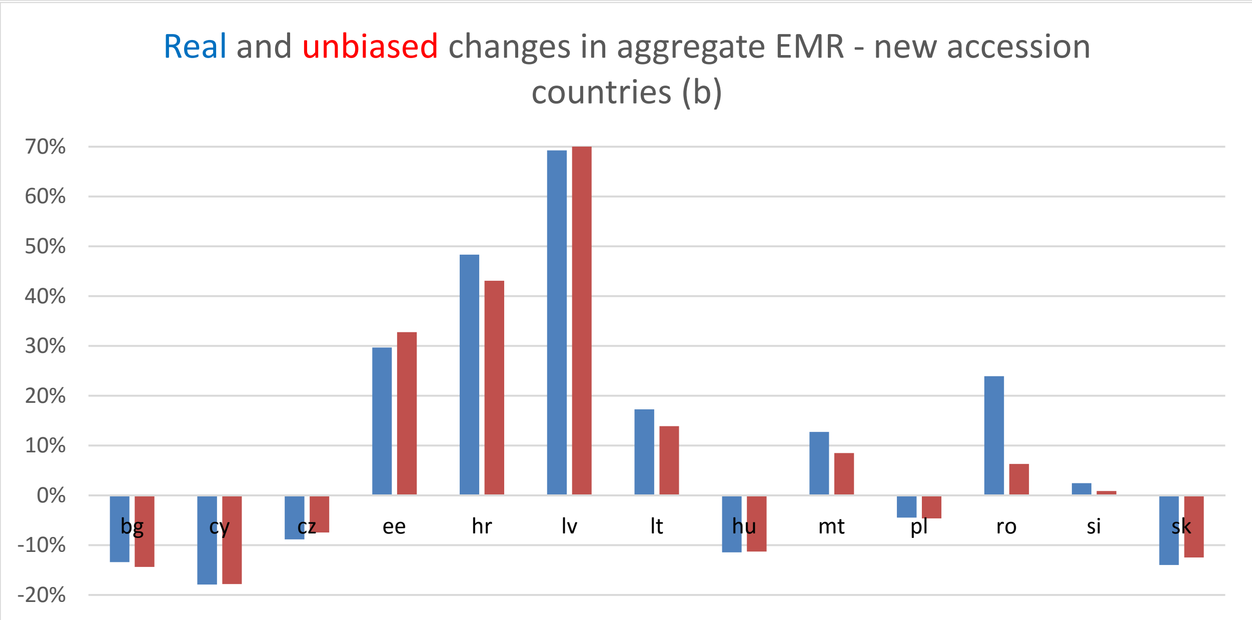


Figure 8a and 8b. Real and unbiased changes in EMR.

With the exception of Italy and Portugal, EU15 countries have improved their metabolic performance. However, if it had not been for the sectorial shift bias, also Ireland Spain and Finland would have worsened their metabolic performance. Only half of new accession countries, on the other hand, have improved their EMR (both in real and unbiased terms), while seven of them –Estonia, Croatia, Latvia, Lithuania, Malta, Romania and Slovenia- have worsened it. Sectorial shifts in new accession countries have been minor –from figure 6 we see that the industrial sector has in general not lost as much as in EU15 countries- and this can be seen in the lower difference between real and unbiased EMR in these countries.

The same analysis can be carried out when studying labour productivity (ELP) in real and unbiased terms. The shift from agriculture and industry towards the service sector in fact allows for not only less energy consumption per hour worked but often also for higher economic productivity which, in turn, further conditions improvements in energy intensity.

Figures 9 and 10 below are the equivalent to 7 and 8, showing the initial, final and unbiased ELP values and their changes in real and unbiased terms.

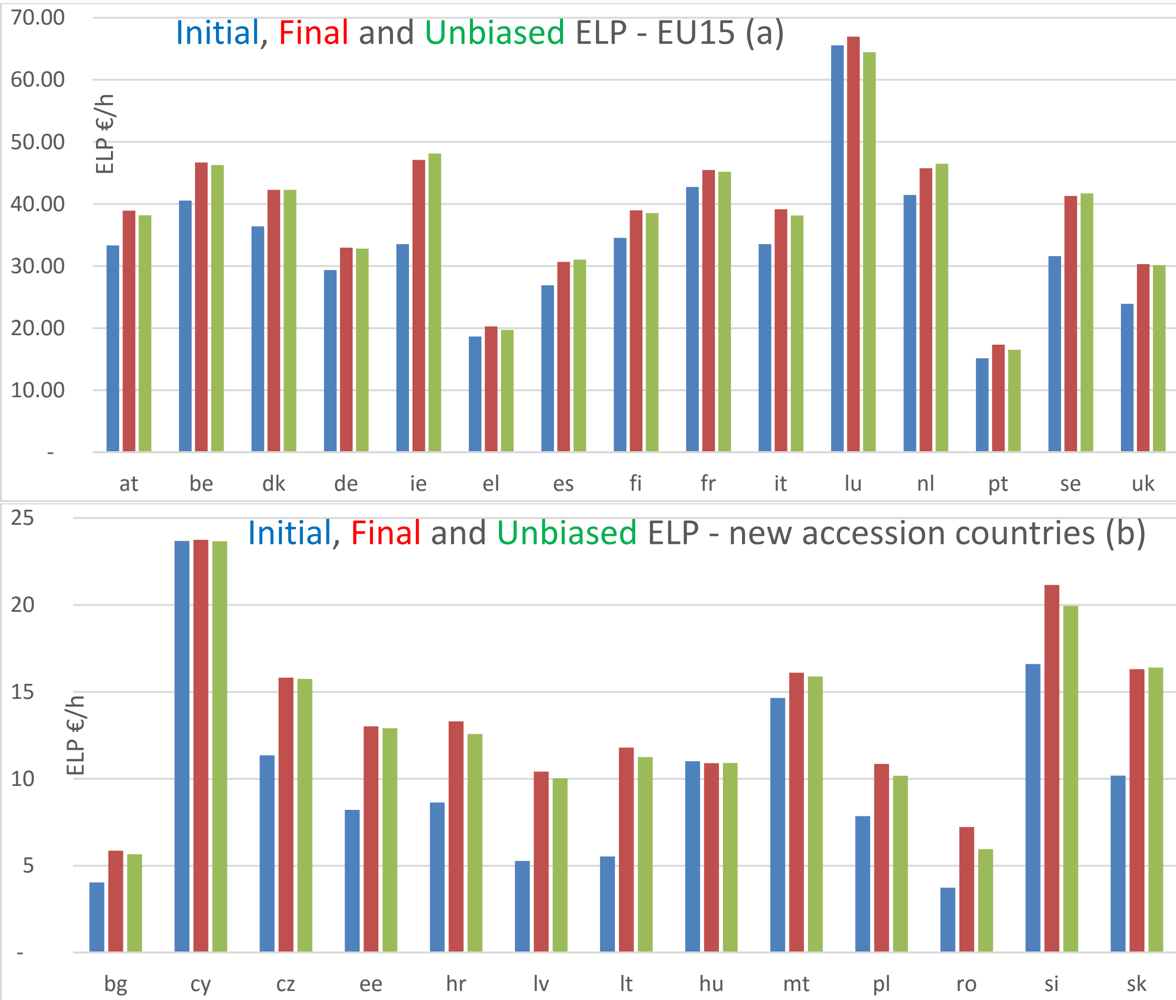


Figure 9a and 9b. ELP aggregate values, at beginning and end of each individual series and unbiased ELP assuming no sectorial shift of labour force.

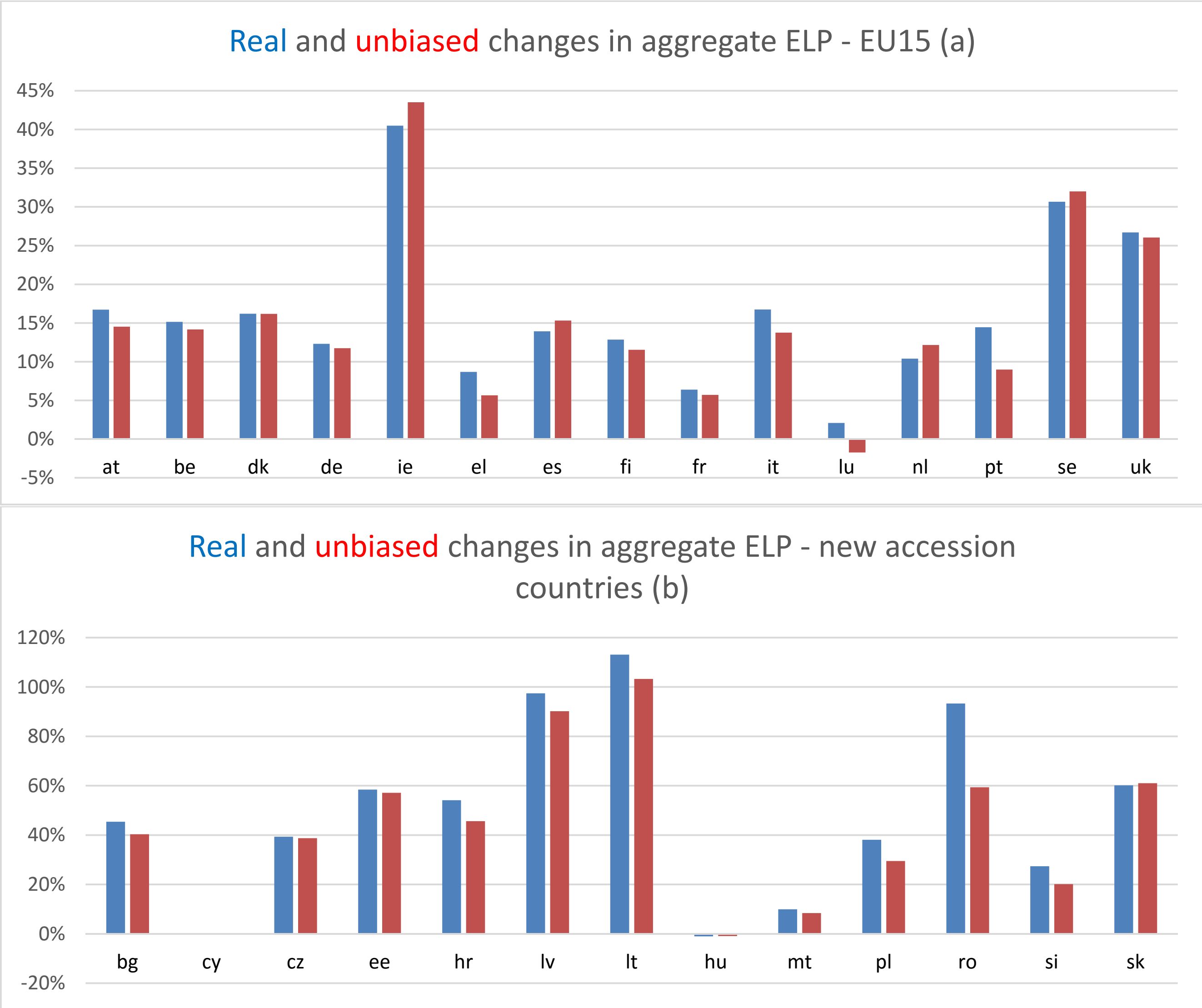


Figure 10. Real and unbiased changes in ELP.

The difference between EU15 and new accession countries is more evident for what concerns labour productivity: for EU15 –except Portugal and Greece- this is always higher than any other new accession country. However, the rapid labour productivity increases in new accession countries (figure 10) shows a convergence path. At EU28 level, the difference between real and unbiased ELP is also lower than the differencve between real and unbiased EMR. This is because a shift of labour force from industry to services decreases dramatically energy consumption but does not necessarily increase labour productivity.

2.3. Unbiased energy intensity

Energy intensity can then be calculated for the unbiased values that result from the thought experiment. So, relating unbiased EMR with unbiased ELP calculated before, we can obtain the unbiased EI. Its values are represented in figure 11 and compared with the values of EI at the start and end of each time series.

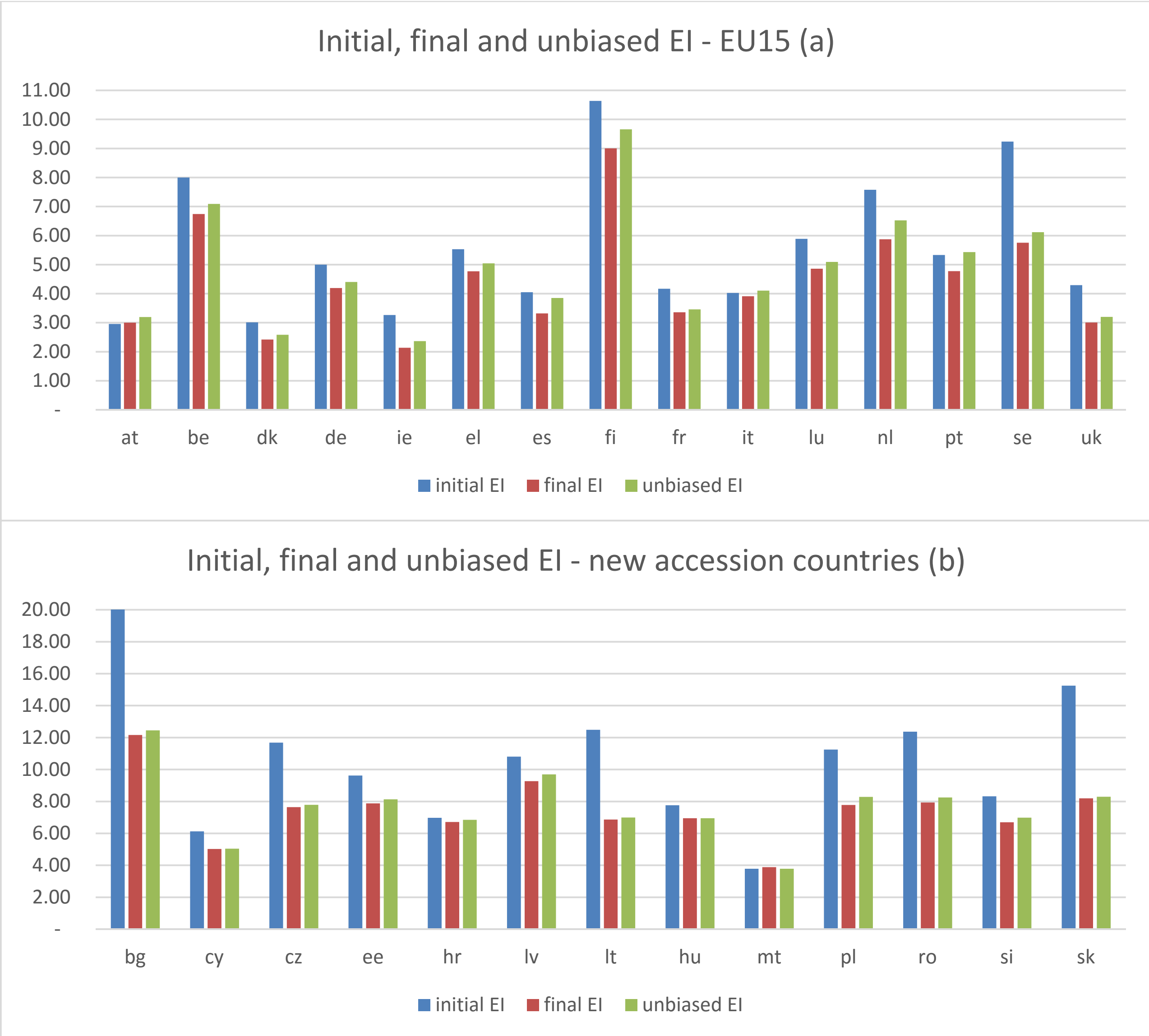


Figure 11a and 11b. Evolution of Energy Intensity, initial, final and unbiased assuming no sectorial shift of labour force.

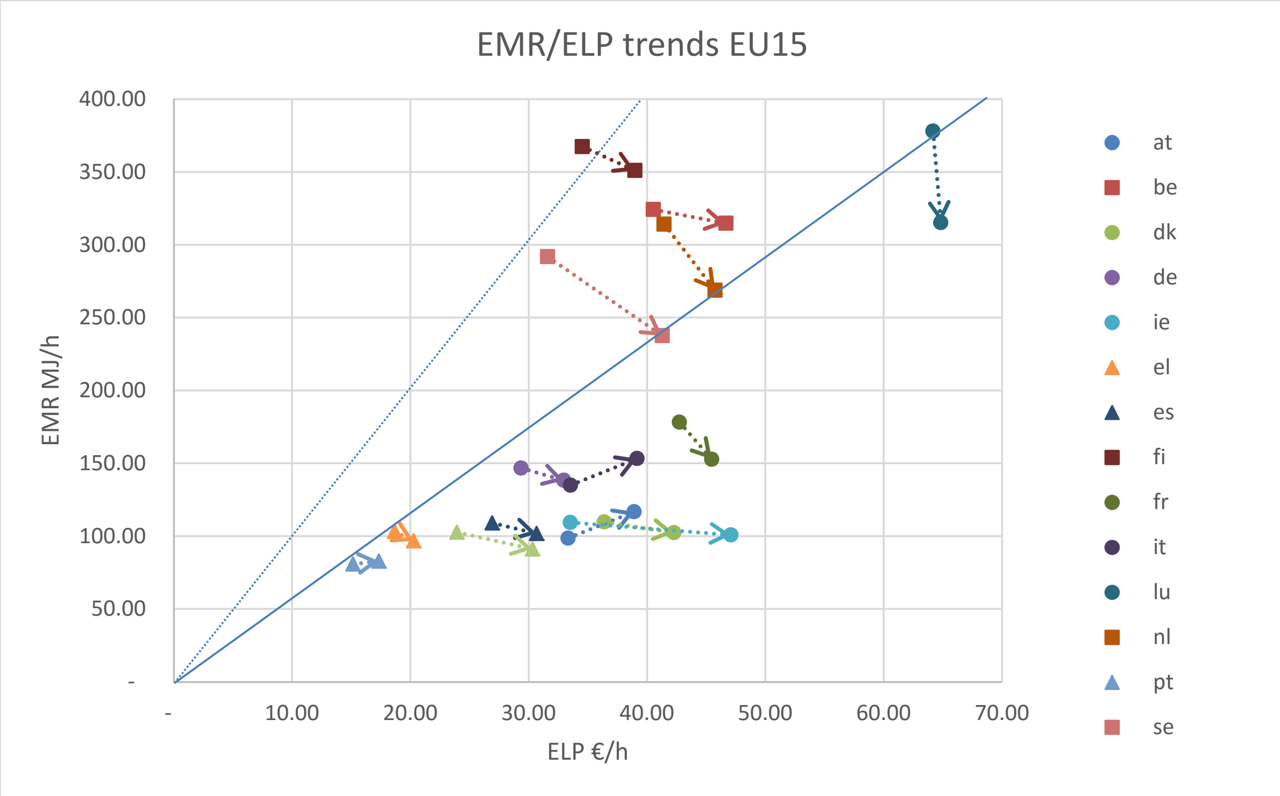
In most cases it has improved, in the sense that less energy is required to generate one euro of economic output. It is however problematic for two reasons:

1. It is a relationship between two flows, that loses the connection with the amount of primary energy consumed per hour of work. As we have seen, Luxembourg has a very high metabolic profile, above 300 MJ/h (figure 7); but because it also has a very high labour productivity, its energy intensity is similar to that of Greece or Portugal which consume much less energy per hour worked ("only" 100 MJ/h) and with a much lower labour productivity (15-20 €/h versus 65 in Luxembourg) (See for instance figure 12a). So, with similar energy intensities they have radically different metabolic and monetary profiles. That is, only looking at the EI indicator, we might not be able to assess if a good EI performance is also associated to an economy with a low metabolic profile which, in the context of environmental and natural resource crisis, is of paramount importance.

Therefore, a better representation of energy intensity is one that plots EMR and ELP on the same graph (see figure 12a and 12b below), in which the EI can be derived by the angle that is formed between each point in the graph and the intercept of the axis. For instance the lines corresponding to EI=5 (full line) and EI=10 (dotted line) have been drawn in the graphs of figure 12a and 12b. Points to the left of this line have higher EI, to the right lower EI. The energy intensity paradox of Luxembourg, Greece and Portugal can be explained in the graph: similar angles connecting the dots correspondent to these three countries with the intercept of the graph imply similar energy intensities. But while Luxembourg is towards the top-right corner of the graph (high metabolic profile and labour productivity), Portugal and Greece are towards the bottom-left (lower metabolic profile and labour productivity).

From both figures 12 it can be seen that there is a general relationship between higher ELP and higher EMR. There are clearly some countries that perform differently, such as Finland, Belgium, Sweden and the Netherlands, for which very high values of energy consumption per hour worked are associated to medium-high labour producivity values, or other countries such as Ireland, Denmark and Austria which have medium-high labour producivity values associated to low values of energy consumption per hour worked.

Finally, the trend over the different time series goes towards higher labour productivity (shift to the right) and sometimes higher, sometimes lower metabolic rate (upwards or downwards shift). For new accession countries, energy consumption per hour worked has increased more frequently than for EU-15 countries.



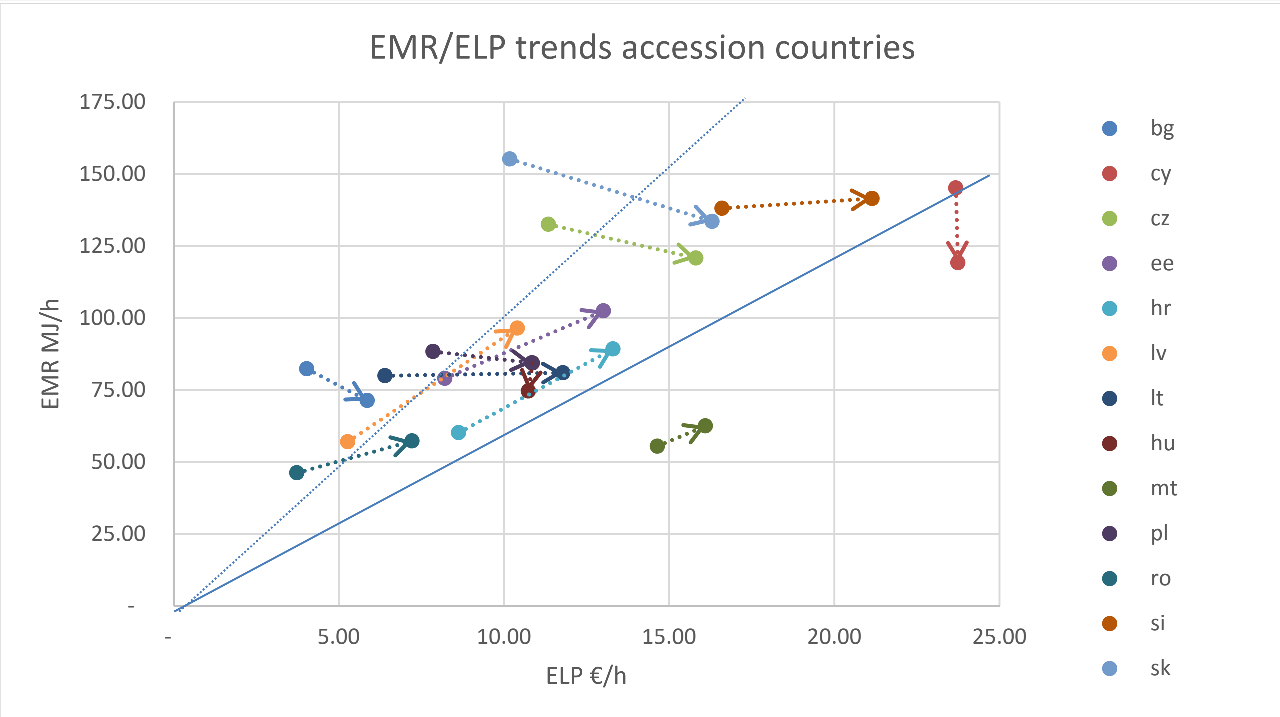


Figure 12a and 12b. Evolution of EMR and ELP in EU15 and accession countries.

2. The second problem related to the evolution of energy intensity is due to the bias that emerges when labour force shifts away from the energy intensive sectors. This is what can be observed when looking in detail at figure 11: except for Malta, had not there been a sectorial shift in employment, energy intensity at the end of the time series would be higher. Figure 13 shows how higher would be energy intensity if labour force had not shifted among sectors. This can be as high a 65% more and very often 20% or more, particularly in the EU15.

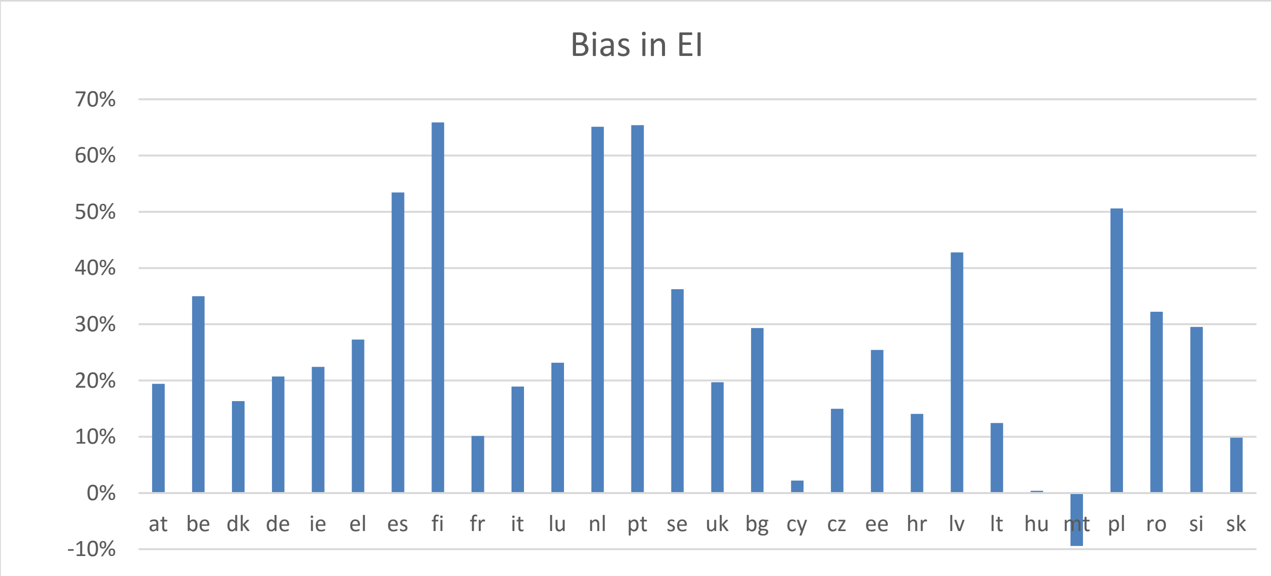
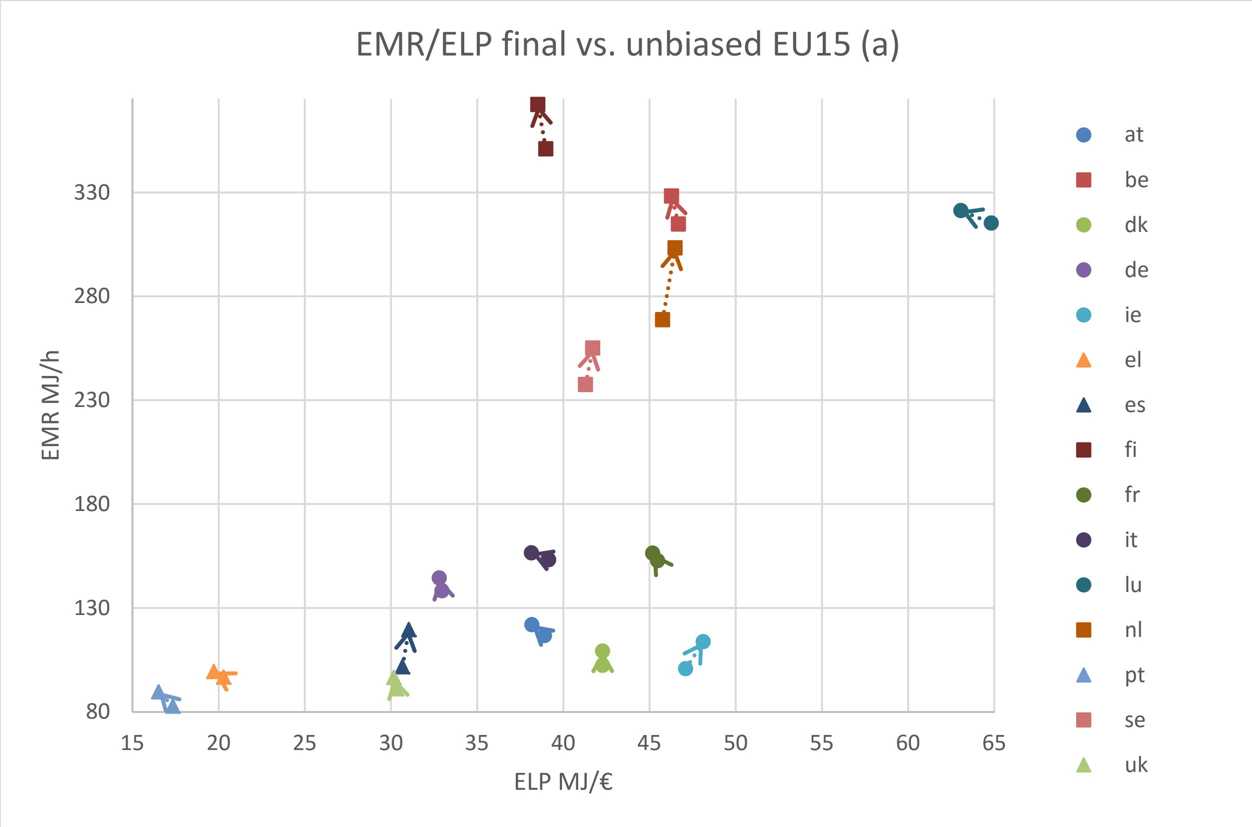


Figure 13. Bias in energy intensity. How much higher would it be without sectorial shifts of employment.

This bias in EI can be then reproduced in one graph where both the EMR and ELP are highlighted. Figure 14a and 14b show for EU-15 and new accession countries the corrected trends in EMR and ELP had there not been a shift in the sectorial composition of labour force. Clearly, with a higher proportion of worked hours still in agriculture or industry, labour productivity would have been lower and, more clearly, energy consumption per hour worked would have been higher, so that energy intensity would have been, overall, higher.



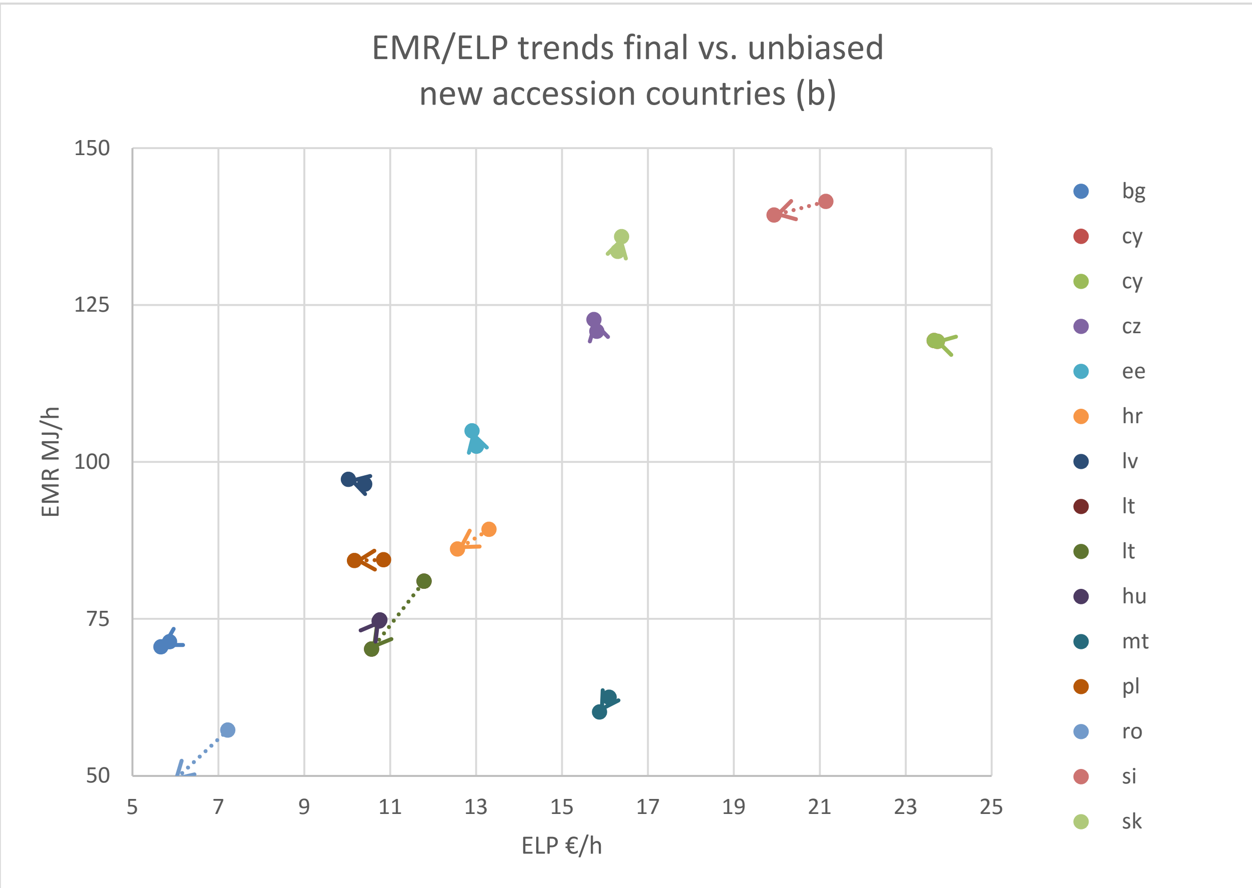


Figure 14a and 14b. Final vs. unbiased EMR and ELP values, EU15 and new accession countries.

Table 4 below represents, for each EU country, the initial (first row), the final (second row) and the unbiased (third row) values of EMR (MJ/h), ELP (€/h) and EI (MJ/€). Moreover, it shows those countries that have increased hours worked throughout their series (names are in bold) and those that have lost hours (names are underlined and in red). As well, those countries where the unbiased EMR would have improved along the series (bold EMR values in the third row of each country) and those where total primary energy consumption has decreased (underlined EMR values in the third row).

The ideal situation would see job creation while at the same time an improvement in unbiased EMR and a decrease in primary energy consumption is observed.

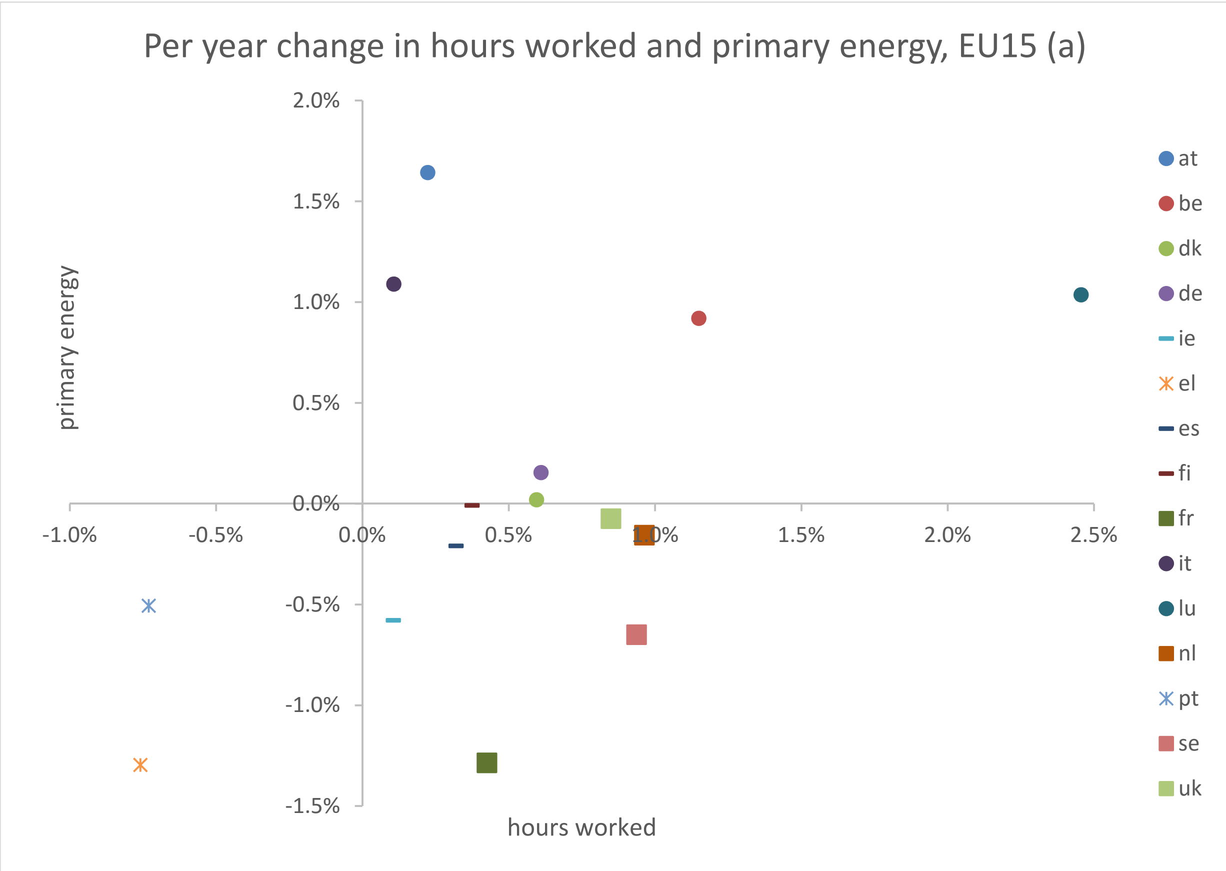
Although there has been job creation in most countries (note that the time series of several countries, particularly of the EU15, end in 2008), those who would have improved their relative metabolic performance (lower values of the unbiased EMR) are only about half: just 8 countries in EU15 and 7 countries among the new accession ones. Those that have improved their absolute metabolic performance (lower consumption of primary energy) are less than half: 8 in the EU15 and 5 in new accession countries.

If we wish to combine the desirable situation of job creation, improved unbiased energy efficiency and decreased total energy consumption, only France, The Netherlands, Sweden and the UK among the EU15 and Bulgaria and Slovakia among the new accession countries have achieved the triple objective.

	Euro/h	MJ/h	MJ/Euro		Euro/h	MJ/h	MJ/Euro
at	33,33	98,61	2,96	bg	4,03	82,35	20,41
	38,91	116,73	3,00		5,87	71,33	12,16
	38,18	121,93	3,19		5,66	**70,53**	12,45
be	40,54	324,22	8,00	cy	23,68	145,16	6,13
	46,68	314,73	6,74		23,74	119,19	5,02
	46,28	328,23	7,09		23,66	**119,33**	5,04
dk	36,39	109,65	3,01	cz	11,35	132,52	11,68
	42,28	102,35	2,42		15,81	120,81	7,64
	42,28	**109,25**	2,58		15,75	**122,66**	7,79
de	29,36	146,73	5,00	ee	8,21	79,04	9,62
	32,97	138,30	4,20		13,01	102,49	7,88
	32,81	**144,42**	4,40		12,91	104,95	8,13
ie	33,53	109,41	3,26	hr	8,63	60,17	6,97
	47,10	100,77	2,14		13,30	89,24	6,71
	48,12	113,74	2,36		12,57	86,10	6,85
el	18,66	103,25	5,53	lv	5,27	56,99	10,81
	20,28	96,73	4,77		10,41	96,45	9,27
	19,72	**99,42**	5,04		10,03	97,21	9,69
es	26,92	109,03	4,05	lt	6,40	79,94	12,48
	30,67	101,79	3,32		11,79	80,98	6,87
	31,04	119,60	3,85		10,57	**70,17**	6,64
fi	34,54	367,41	10,64	hu	10,86	84,34	7,76
	38,98	350,96	9,00		10,74	74,65	6,95
	38,53	372,24	9,66		10,76	**74,82**	6,95
fr	42,74	178,24	4,17	mt	14,65	55,44	3,79
	45,47	152,71	3,36		16,10	62,50	3,88
	45,19	**156,32**	3,46		15,88	60,15	3,79
it	33,54	134,98	4,02	pl	7,86	88,36	11,25
	39,16	153,23	3,91		10,85	84,41	7,78
	38,15	156,52	4,10		10,17	**84,28**	8,29
lu	64,17	377,98	5,89	ro	3,74	46,21	12,37
	64,84	315,24	4,86		7,22	57,26	7,93
	63,07	**321,25**	5,09		5,95	49,13	8,25
nl	41,45	314,10	7,58	si	16,60	138,11	8,32
	45,76	268,73	5,87		21,14	141,49	6,69
	46,49	**303,28**	6,52		19,94	139,32	6,99
pt	15,15	80,80	5,33	sk	10,18	155,22	15,25
	17,35	82,82	4,77		16,30	133,53	8,19
	16,52	89,67	5,43		16,39	**135,88**	8,29
se	31,60	291,85	9,24				
	41,29	237,55	5,75				
	41,71	**255,07**	6,12				
uk	23,93	102,69	4,29				
	30,32	91,12	3,01				
	30,16	**96,59**	3,20				

Table 4. Initial, final and theoretical unbiased values of EMR, ELP and EI per each EU country.

This can also be seen graphically, as in figure 15a and 15b. Note that the two graphs reproduce changes in employment and in primary energy without considering the bias due to sectorial adjustment of employment. This is particularly relevant for the EU 15 for which, Spain, Finland and Ireland have decreased their primary energy consumption but would have not in case labour force had not moved away from the industrial sector. On the other hand Portugal and Greece have improved their energetic metabolism but at the cost of losing jobs. For new accession countries, the situation is worse. Although less affected from the bias associated to a redistribution of labour force, nearly half of these countries have lost jobs. Three of them, Estonia, Latvia and Slovenia, have both lost jobs without improving their metabolic position.



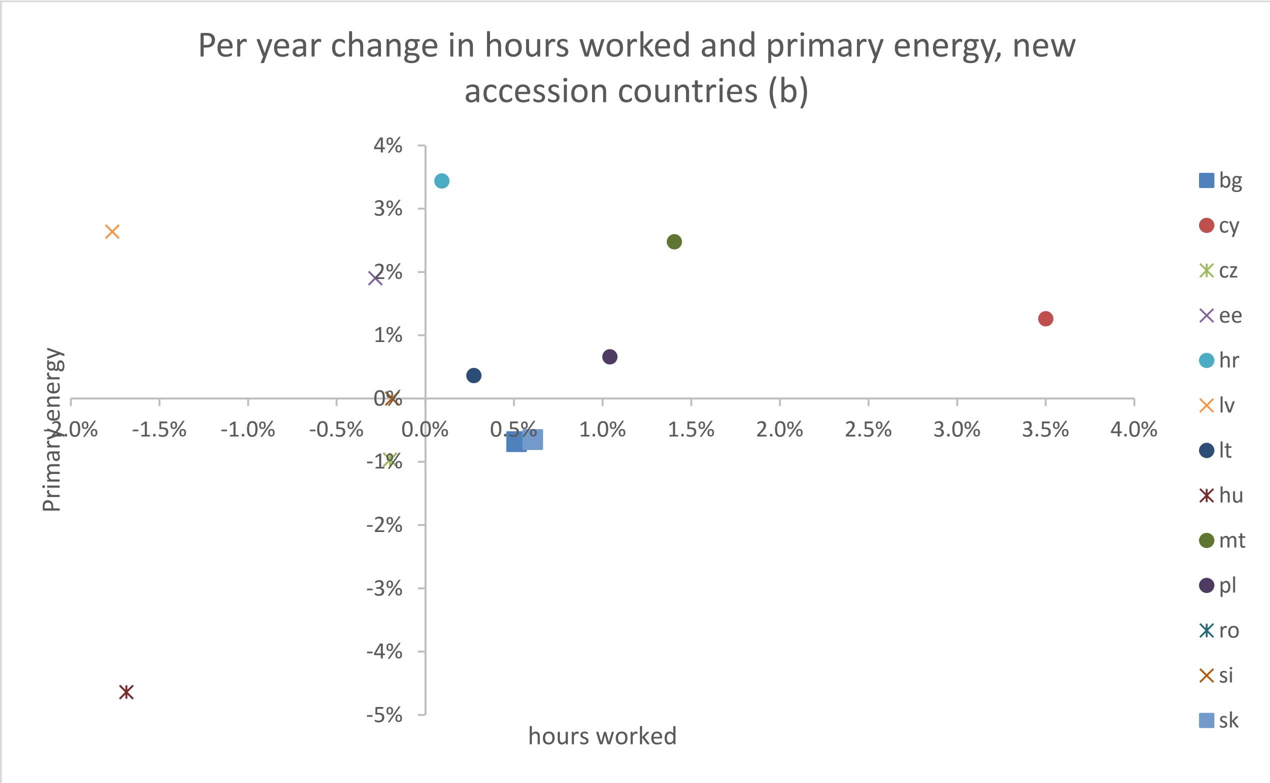


Figure 15a and 15b. Per-year change in worked hours and primary energy consumption, EU15 and new accession countries.

3. Conclusion to part I

Energy efficiency is not a good measure of the progress towards greening of EU economies. Particularly because its improvements are biased by the structural adjustments of the economies.

In almost all EU countries, both agriculture and productive sectors have lost weight relative to the total of paid-work hours. In all EU countries the service and government sector has grown in relative to the total of paid-work hours.

This implies that improvements in the energy consumption per hour worked - exosomatic metabolic rate (EMR) of paid work- depend on technological improvements (desirable outcome) but also on the sectorial shift (illusionary outcome).

In this study we run a simulation assuming the % of hours in the three sectors did not change over time, to see what would be the unbiased EMR, unbiased ELP and unbiased EI. It is shown that in most cases unbiased EMR and unbiased EI would be higher than the actual.

Because of international trade, less labour force in agriculture and industry does not entail less consumption of material products among EU consumers, but simply an increase in the imports of these energy intensive products. Although Energy Intensity is improving, dematerialization and a decoupling of GDP from material consumption are not occurring. From a perspective of job creation relocation of agricultural and industrial employment would be socially desirable. In alternative, if labour force in agriculture and industry is destined to shrink, and since labour productivity grows in general faster than paid-work hours, incentives towards work sharing could allow for job creation in a situation of shrinking paid-work hours and in a post-growth economy.

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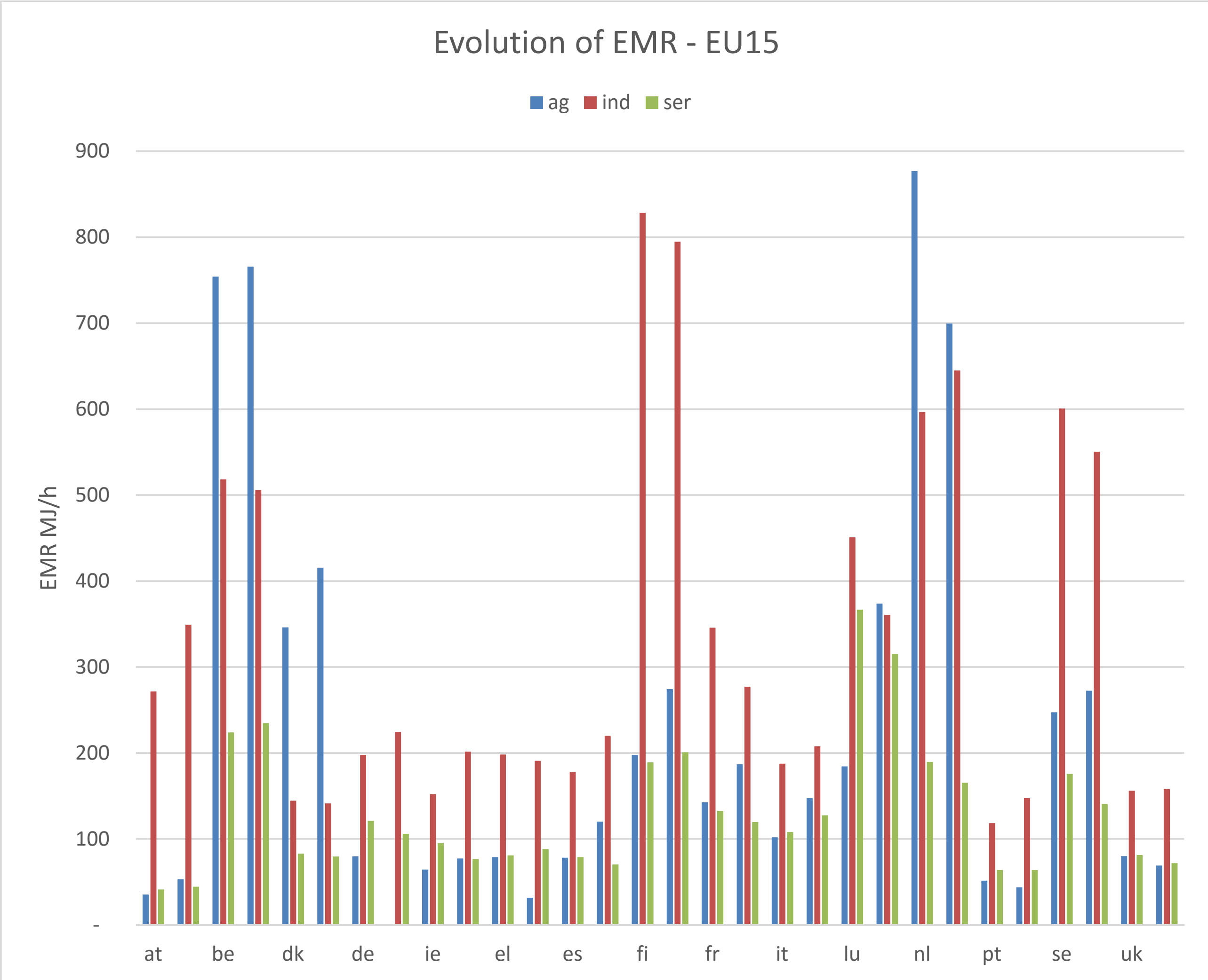
Appendix 1. Initial and final values of ELP, EMR and EI per each country and sector

	Euro/hour				MJ/hour				MJ/Euro			
	ELP	**ag**	**ps**	**s&g**	**EMR**	**ag**	**ps**	**s&g**	**EI**	**ag**	**ps**	**s&g**
at	33	6	42	34	99	35	272	41	3,0	5,5	6,5	1,2
	39	9	48	39	117	53	349	44	3,0	5,9	7,3	1,1
be	41	22	40	41	324	754	518	224	8,0	34,3	12,9	5,4
	47	21	44	48	315	766	506	235	6,7	37,2	11,6	4,8
dk	36	30	35	37	110	346	144	83	3,0	11,5	4,1	2,2
	42	16	49	41	102	415	141	80	2,4	25,6	2,9	1,9
de	29	9	27	32	147	80	198	121	5,0	8,4	7,2	3,8
	33	13	34	33	138	-	224	106	4,2	-	6,6	3,2
ie	34	11	40	34	109	64	152	95	3,3	5,9	3,8	2,8
	47	11	66	45	101	77	202	77	2,1	7,3	3,1	1,7
el	19	7	20	21	103	79	198	81	5,5	10,7	9,8	3,9
	20	6	22	22	97	32	191	88	4,8	5,1	8,6	4,0
es	27	16	27	28	109	78	178	79	4,1	4,8	6,6	2,8
	31	18	36	30	102	120	220	70	3,3	6,5	6,2	2,3
fi	35	13	45	33	367	198	828	189	10,6	14,9	18,4	5,7
	39	17	43	40	351	274	795	201	9,0	16,2	18,5	5,1
fr	43	17	45	44	178	143	346	133	4,2	8,2	7,8	3,0
	45	21	46	47	153	187	277	120	3,4	8,9	6,0	2,6
it	34	16	28	39	135	102	187	108	4,0	6,5	6,6	2,8
	39	18	33	44	153	147	208	127	3,9	8,2	6,3	2,9
lu	64	26	45	74	378	184	451	367	5,9	7,1	10,1	4,9
	65	22	36	76	315	374	361	315	4,9	16,8	10,1	4,1
nl	41	37	41	42	314	877	597	190	7,6	23,9	14,4	4,5
	46	27	55	44	269	699	645	165	5,9	25,5	11,7	3,7
pt	15	5	13	19	81	51	118	64	5,3	10,9	9,4	3,4
	17	4	15	20	83	44	147	64	4,8	10,4	9,5	3,2
se	32	23	37	30	292	247	601	176	9,2	10,6	16,2	5,9
	41	25	53	38	238	272	550	141	5,8	10,8	10,4	3,7
uk	24	16	25	24	103	80	156	81	4,3	5,0	6,2	3,4
	30	13	30	31	91	69	158	72	3,0	5,2	5,3	2,3
bg	4	2	4	5	82	21	185	50	20,4	8,9	50,5	10,1
	6	2	7	7	71	16	121	65	12,2	8,7	18,6	9,5
cy	24	20	20	25	145	24	239	121	6,1	1,2	12,1	4,8
	24	12	22	25	119	99	129	117	5,0	8,4	6,0	4,7
cz	11	8	11	12	133	110	200	88	11,7	14,2	18,4	7,3
	16	12	16	16	121	139	161	95	7,6	11,9	10,2	5,9
ee	8	5	7	9	79	49	108	67	9,6	9,7	15,3	7,3
	13	11	12	14	102	158	118	91	7,9	14,7	9,6	6,7
hr	9	3	9	11	60	22	97	54	7,0	7,5	10,7	5,1
	13	5	12	16	89	45	122	82	6,7	9,3	10,1	5,1
lv	5	2	5	6	57	34	76	54	10,8	17,7	14,0	9,1
	10	5	10	11	96	82	142	82	9,3	17,7	13,9	7,3
lt	6	3	16	6	80	24	246	69	12,5	8,7	15,7	11,5
	12	6	14	12	81	39	113	74	6,9	6,9	8,2	6,2
hu	11	6	11	12	84	69	94	83	7,8	11,4	8,8	7,1
	11	7	11	11	75	54	80	76	6,9	8,1	7,3	6,7
mt	15	7	15	15	55	19	32	68	3,8	2,8	2,1	4,5
	16	5	15	17	63	20	45	69	3,9	4,2	3,1	4,0
pl	8	1	8	10	88	66	147	59	11,2	46,6	18,3	5,7
	11	3	12	12	84	73	103	76	7,8	27,4	8,9	6,3
ro	4	1	4	7	46	4	117	40	12,4	3,4	26,3	5,8
	7	1	9	9	57	9	103	55	7,9	6,3	11,4	5,8
si	17	3	17	21	138	24	198	136	8,3	7,4	11,8	6,4
	21	4	24	23	141	36	204	130	6,7	8,6	8,6	5,7
sk	10	7	11	10	155	66	261	106	15,2	9,6	23,7	10,6
	16	17	18	15	134	82	243	82	8,2	4,8	13,5	5,3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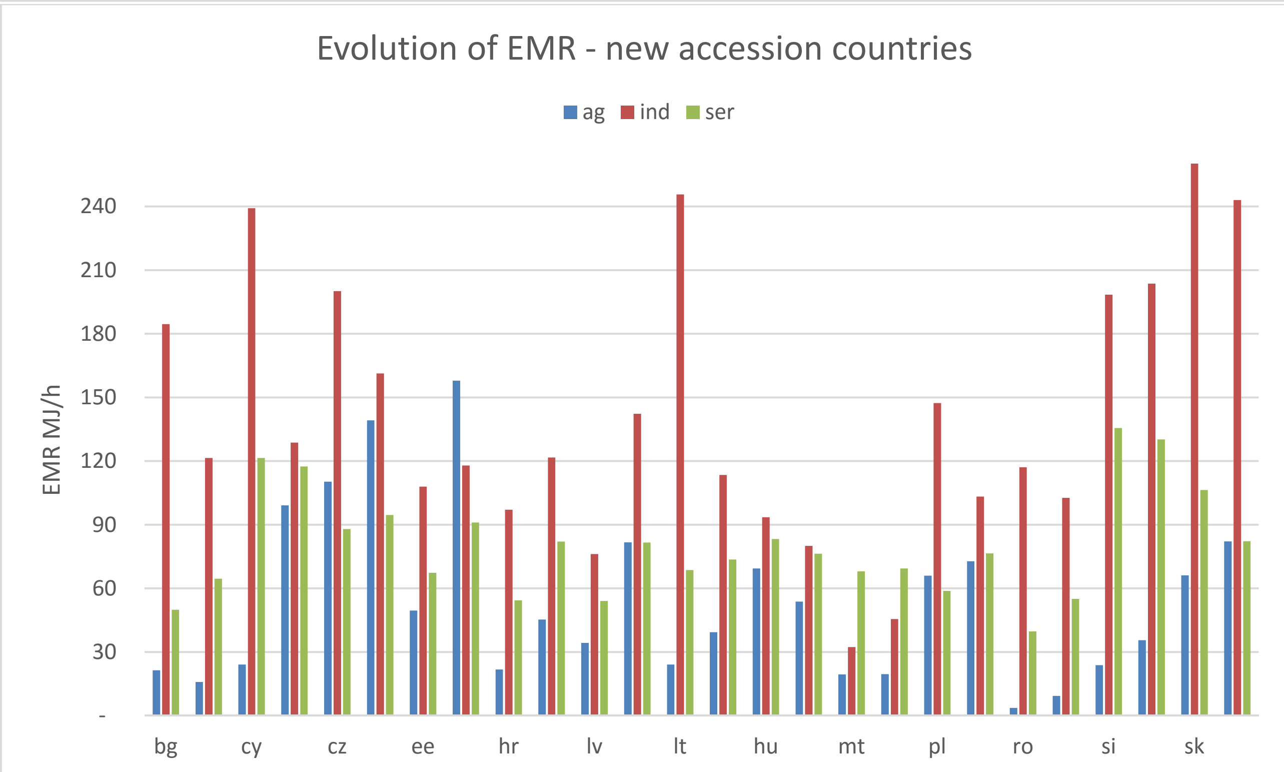
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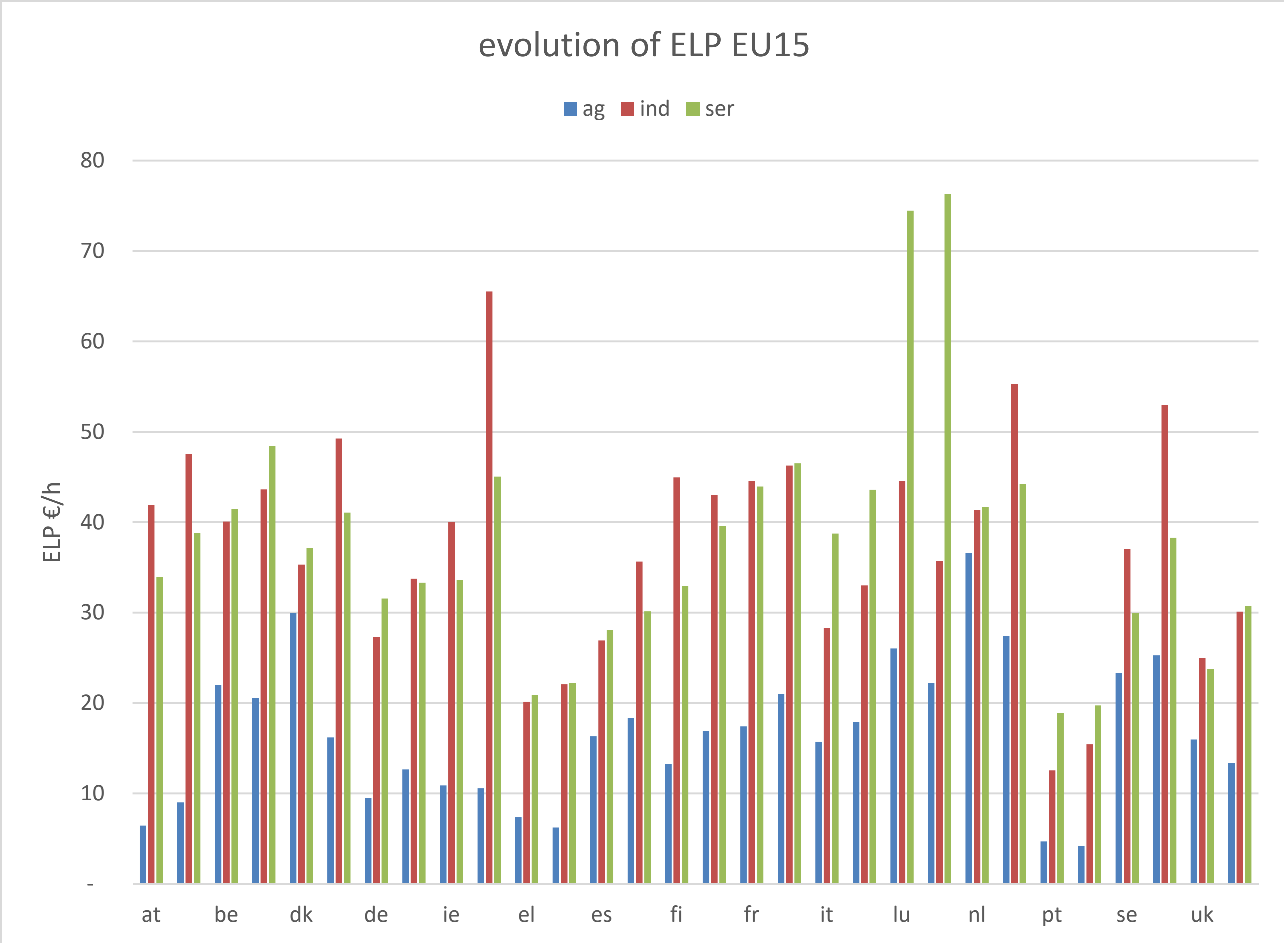
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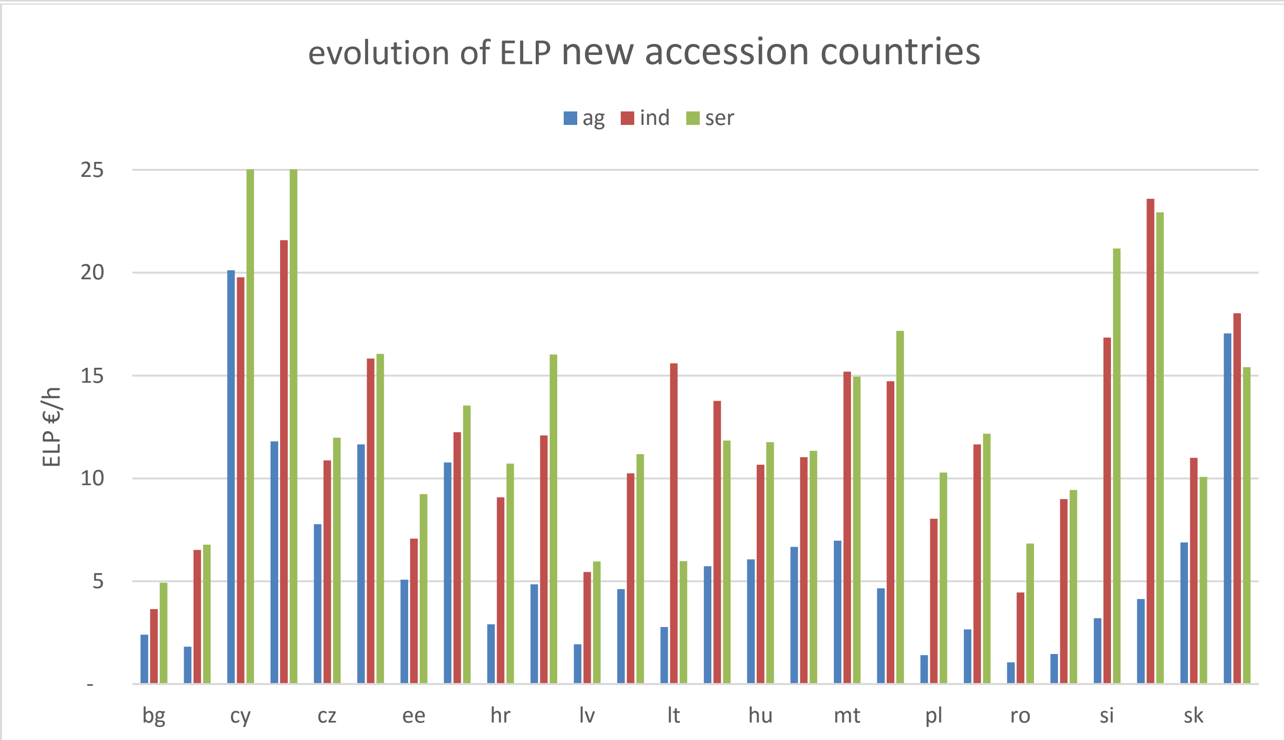
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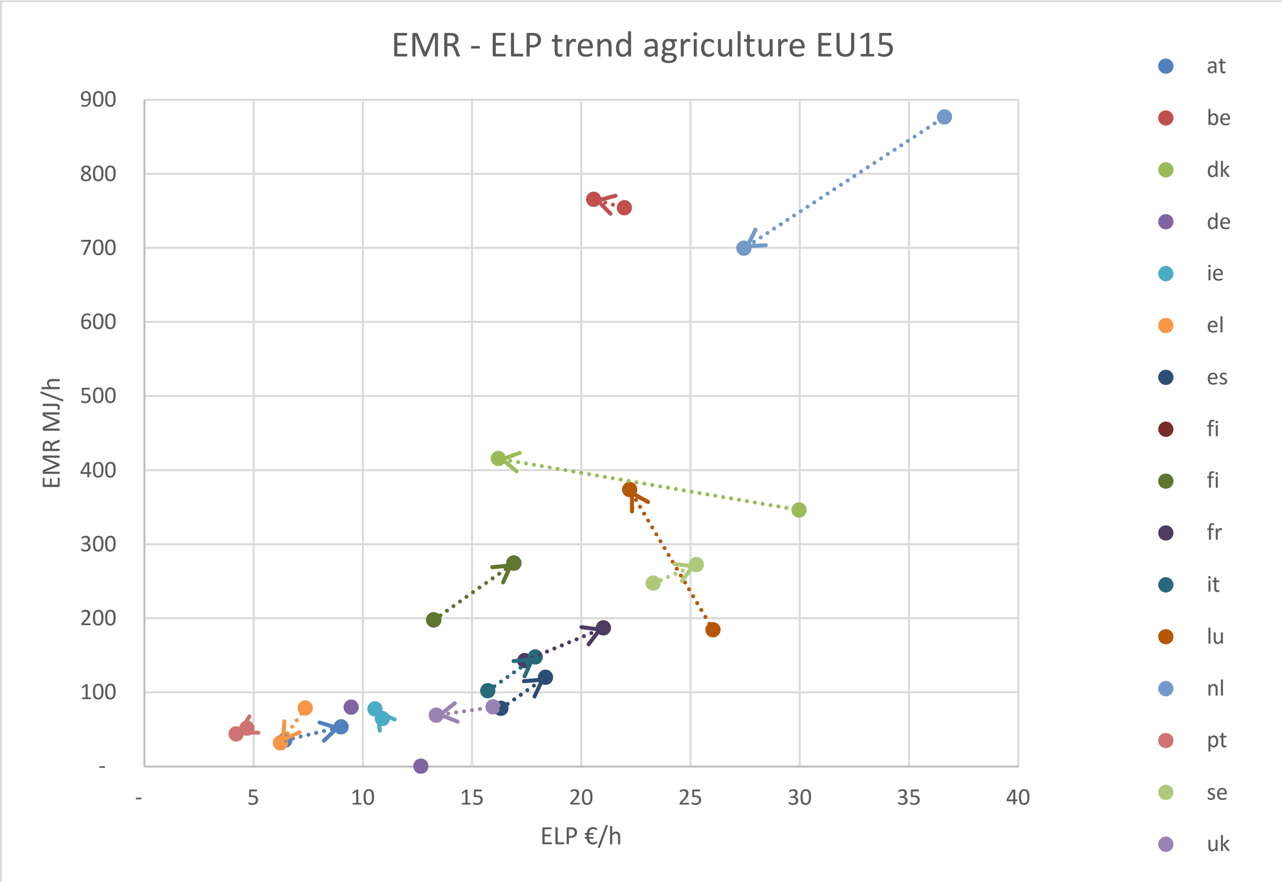
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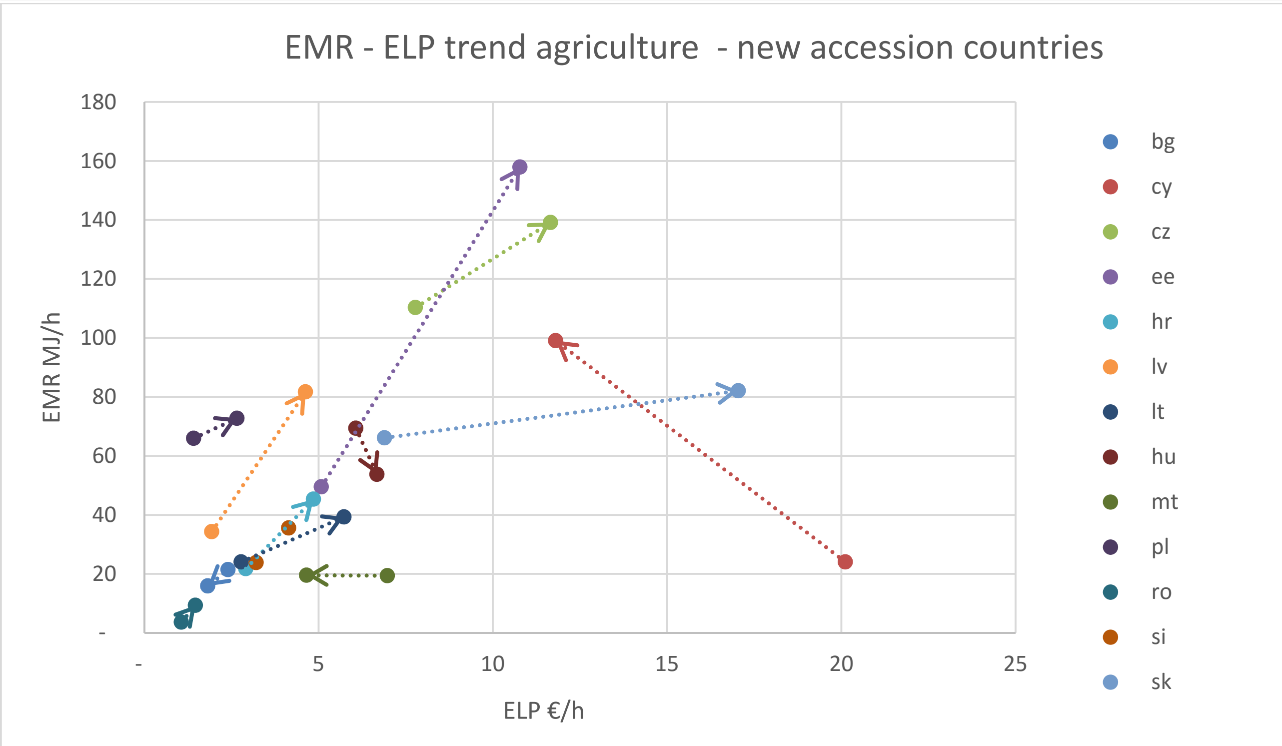
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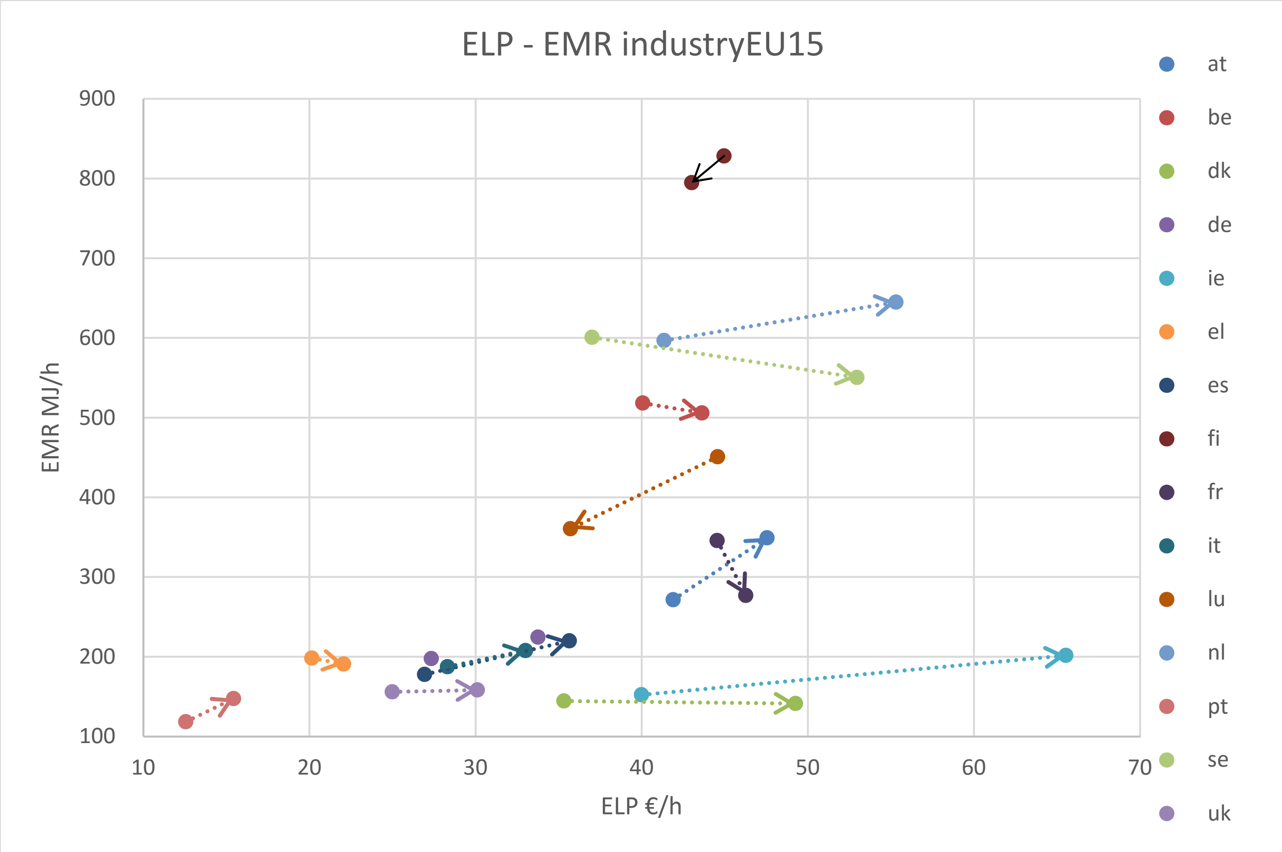
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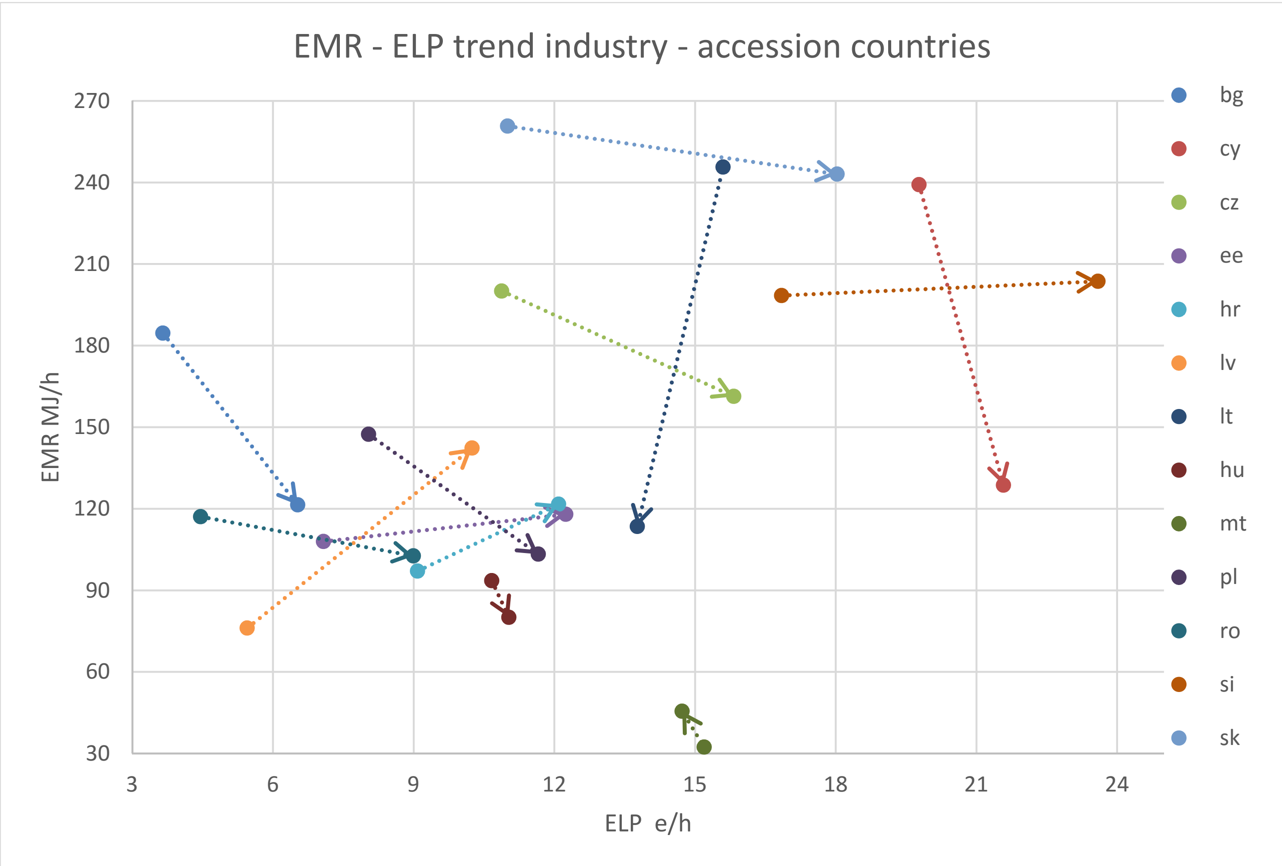
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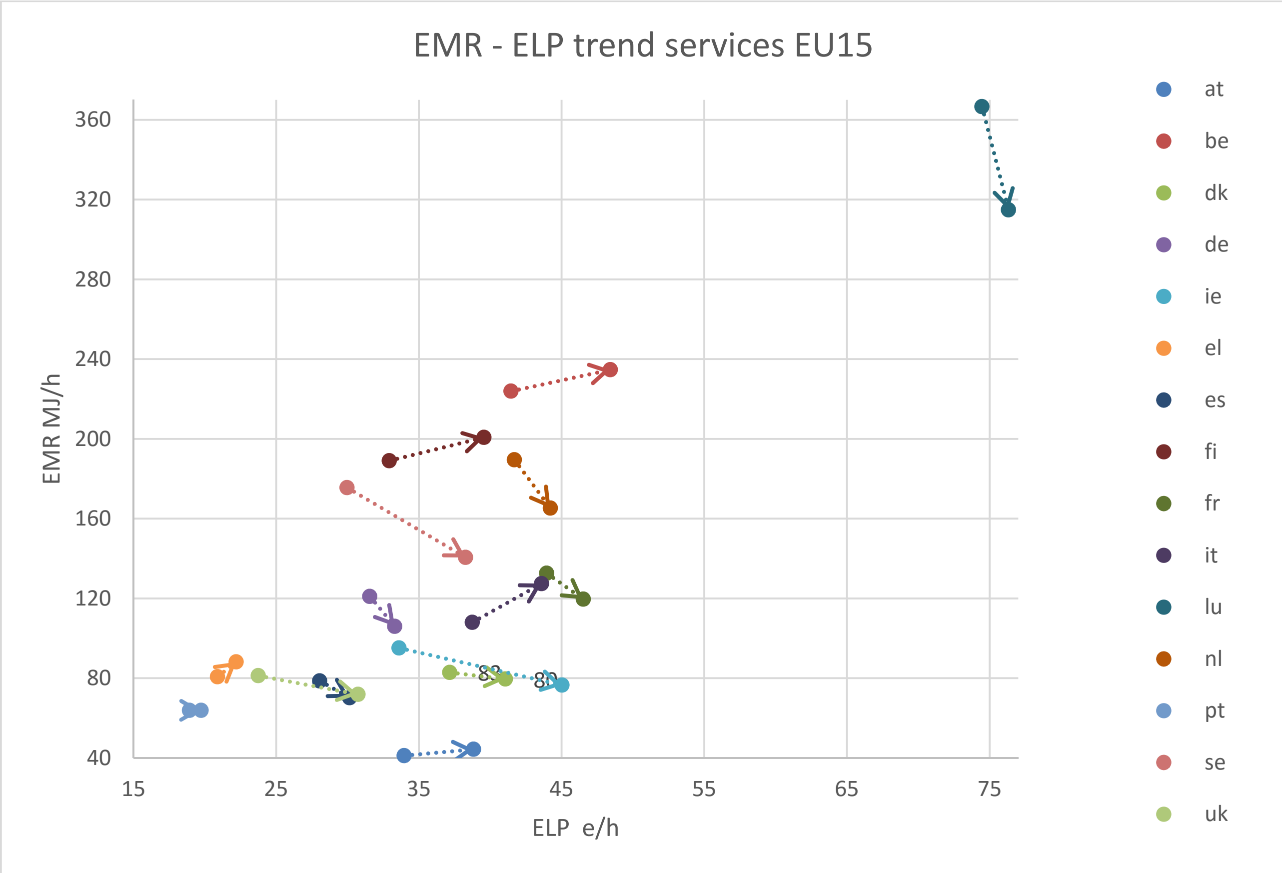
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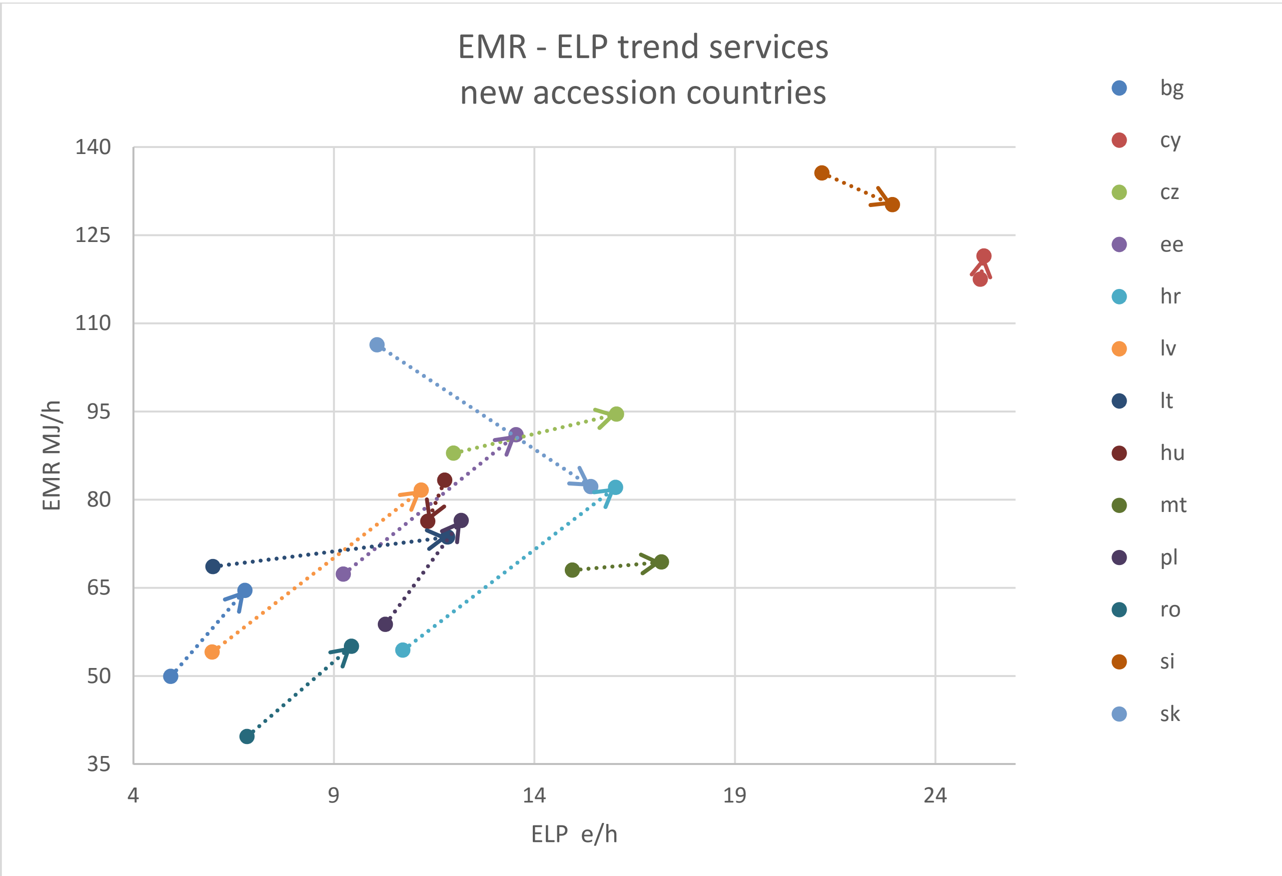
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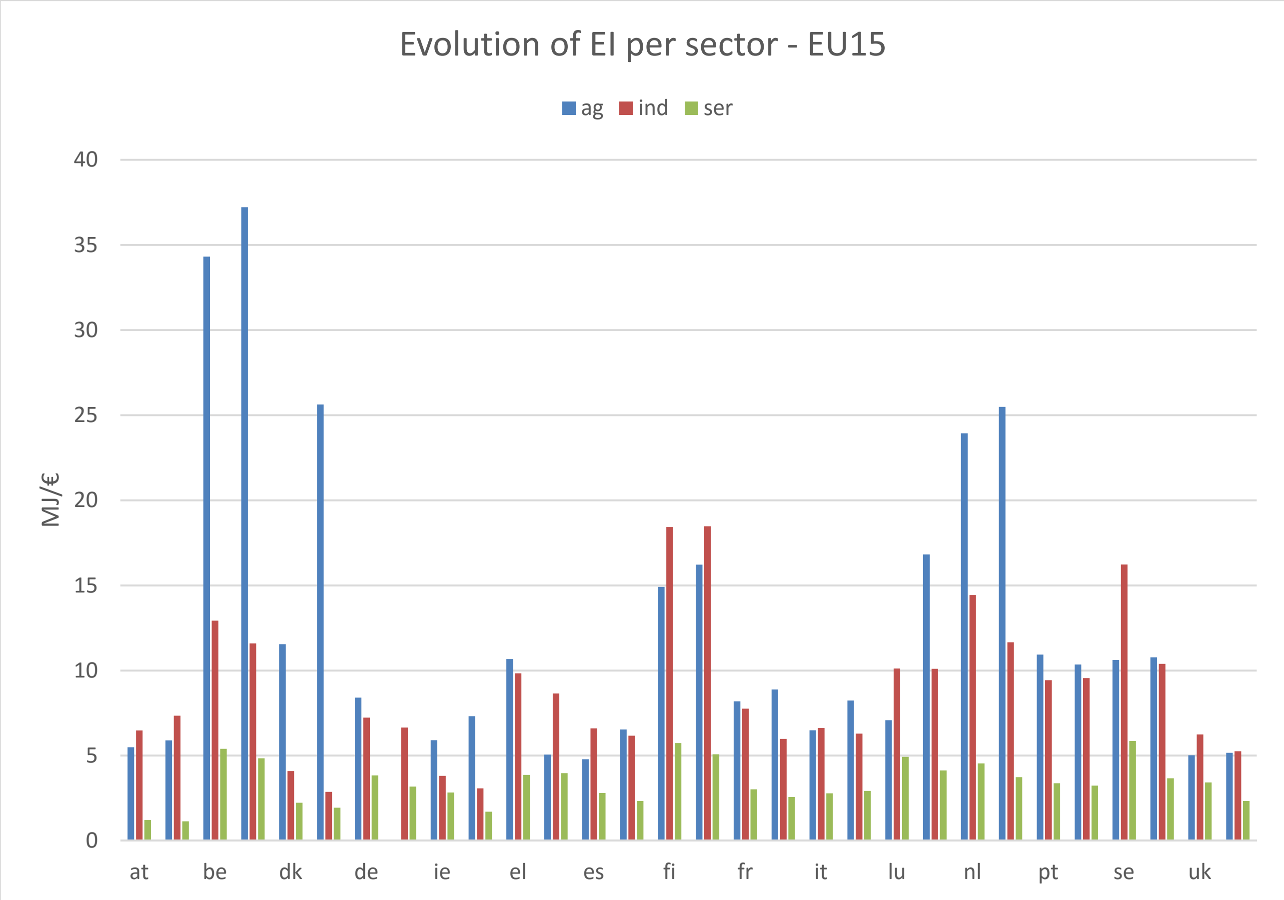

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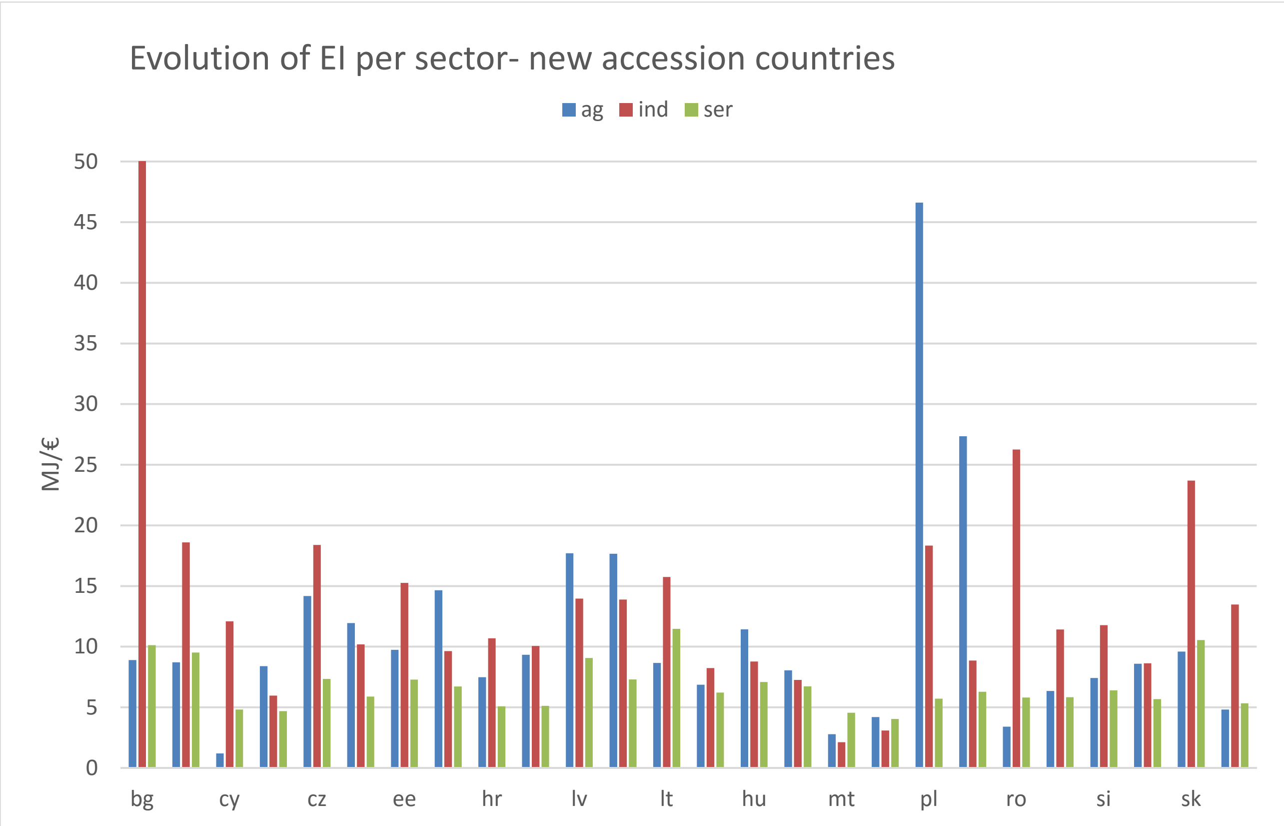

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Appendix 2. Method - management and handling of available data

The main sources for data gathering have been EUROSTAT, which in theory supplies information on added value, final energy consumption and work time. However, the three indicators needed adjustments.

1. Work time statistics are missing for many countries, so that the website of the International Labour Organization has been used as a reference (http://www.ilo.org/emppolicy/lang--en/index.htm), in which the number of employees "total employment by economic activity, 2B" and the average hours worked per week "hours of work per economic activity, 4a" are available for all countries and sectors. In order to determine the total number of hours worked. In order to determine the total amount of hours, the product has been multiplied by 47.5, which corresponds to the average weeks worked per year given that, for EU countries, annual leave is of 23 days on average, (ILO, 1995, p. 19). Since there are also a lot of missing data on the average hours worked per week, if these were missing for one year, the values of the closest year have been chosen; if these were missing for a sector, the sectorial average or the general average have been chosen.
   Once the ILO-based data set has been defined, values have been copy-pasted in the Eurostat-based data set. However, no information was available for years more recent than 2008 so that, in cases such as Belgium, Denmark, Sweden UK, Cyprus, Croatia where Eurostat work time data are missing, the analysis ends in 2008.
   For those countries where both Eurostat and ILO data are available, the coherence between the two series is not entirely good. For example, in Germany and Italy Eurostat data are available only for years 2010-2012 and 2011-2012 respectively. While in Germany ILO-based values for 2008 are 26% higher than Eurostat-based values for year 2010, in Italy they are 13% lower. This is a too large error that distorts the data, so that the time series of analysis of these two countries ends in 2008. On the other hand, a quite good coherence between the two sources is found for Lithuania (±3%) when data are available from both sources (2004-2008). Finally, for the Netherlands, although ILO-data for 2008 is only 5% lower than Eurostat-data for 2010, incoherencies arise within sectors: ILO-data are lower in agriculture (15%) and in service and government (8%) but

12% higher in productive sectors. Finally for Poland ILO-based 2007 is 11% lower than Eurostat-based 2008.

2. Added value information has been recalculated applying the GDP deflator series provided by AMECO in order to make it at constant prices (European Commission, Economic and Financial Affairs webpage http://ec.europa.eu/economy_finance/db_indicators/ameco/zipped_en.htm)
3. Energy statistics face a quite large problem because no distinction is made between energy and exergy consumption (Giampietro et al., 2013). Sorman (2011) explains that while Eurostat data offer values of final energy consumption, the total supply in primary energy sources is larger and depends on the energy mix of an economy. That is, Eurostat data account for electricity or gasoline consumption; but since these two energy carriers are not found in nature, they have to be transformed by the energy sector from primary energy sources. This transformation entails a conversion loss. For instance burning coal to produce electricity, or refining oil to produce gasoline or diesel entails a loss which must be accounted. Depending on the energy mix, each country has a different ratio of conversion. In Appendix 2, Sorman offers the conversion efficiency of three energy carriers (electricity, heat and fuel) from the primary energy supply. As well, it offers for year 2007 for each economy of EU15 the percentage used by these energy carriers in the three sectors. Primary energy supply of an economy is then determined by multiplying the proportion of final energy consumption in electricity, heat and fuel by the correspondent value of conversion efficiency for each sector. For the rest of EU countries included in this study, the conversion efficiencies of electricity, heat and fuel production, as well as the relative contribution of these energy carriers in each sector have been calculated based on the average of the EU15 economies. This step is very important since primary energy supply can be as much as twice the final energy consumption. Moreover, due to the high conversion inefficiency of electricity production, the more electrified an economy, the higher will be the energy loss from primary to final energy, unless more efficient power plants (i.e. combined heat and power) are put in place.

Sectorial division in Eurostat data is more articulated than the one used in this report. While here we have used the well-known division between primary (agriculture), secondary (productive sectors) and tertiary (service and government) sector, primary data is divided between seven sectors, combined in this way: “agriculture and forestry” and “fishing” compose the agriculture sector; “industry” composes the productive sector, “services”, “other” and half of “transport” composes the service and government sector. We only include half of the energy consumed by the transport sector based on the Catalonia case study, where the same ratio applies: according to this study, 50% of energy in transport goes to the service and government sector while the other half would be accounted as personal transport (Ramos-Martin et al., 2009; D’Alisa and Cattaneo, 2012), which goes beyond the scope of this study.

PART II: The EUROGREEN model of job creation in a post-growth economy

Executive summary of part II

The EUROGREEN model

This report presents the current state of progress of the EUROGREEN macroeconomic model, which is being developed to provide a concrete understanding of some important policy challenges associated with the transition to ecologically sustainable and socially equitable post-growth societies in the European Union. The model aims to test, in a formal setting, the effectiveness and coherence of Green economic policies, to support the creation of widely attractive narratives about possible futures. For this purpose, the model generates a range of scenarios from the present (2014) to the year 2050. The focus lies on a subset of challenges for attaining the overall goal of sustainable prosperity, namely full employment (or – more broadly – decent livelihoods), low inequality, fiscal sustainability, and a sustainable energy system. In particular, we analyse how the implementation of low-carbon policies is likely to impact upon current trends toward industrial automation and technological unemployment. We also focus on how the implementation of such policies may change the political economy of Working Time Reduction (WTR) and work sharing, in comparison with recent history. EUROGREEN is part of the new field of ecological macroeconomics, and is based on post-Keynesian economics and system dynamics. Data for the French economy provide the empirical basis for the current version of the model.

Can we still expect relatively high GDP growth rates in Europe?

The three baseline scenarios of the EUROGREEN model generate average annual growth rates of GDP for the period 2018-2050 ranging from 0.36% to 1.3% (see Figure S.1). This is significantly lower than the OECD's projections for France of 2.3% for

2018-2030 and 1.4% for 2031-2060.[4] This difference is due to the distinct approaches adopted.[5] In particular, we assume a demand-driven economy and the presence of unemployment that shrinks effective demand, and this allows us to clarify the links between automation and the demand for labour. In the EUROGREEN baseline, annual GDP growth higher than 1% is sustained by labour productivity growth (including automation), which causes a rise in unemployment up to 15%.[6] This means that the increase in aggregate demand is not able to absorb technological unemployment. The main implication is that policies aiming at fostering economic growth can be ineffective, and even in the case that they are able to produce relatively high rates of growth, the economy encounters social and environmental constraints. Therefore, we shift the focus to the management of a post-growth society.

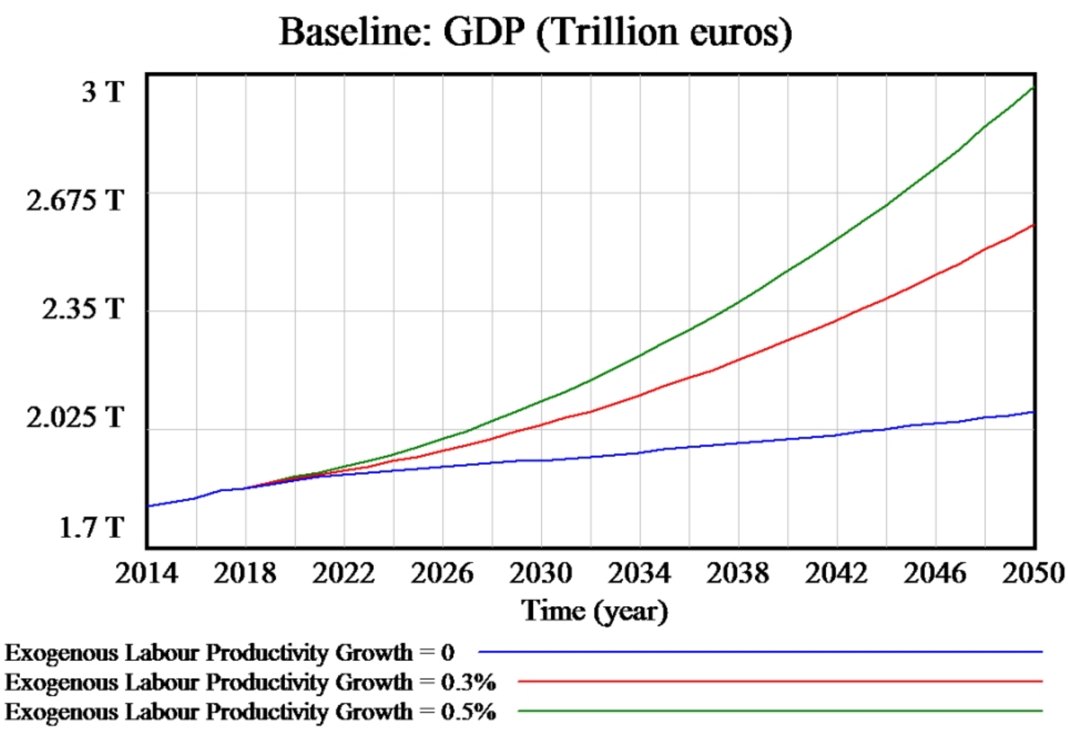

Figure S.1. GDP in the baseline scenarios (trillion euros in constant prices).

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[4] Braconier, H., Nicoletti, G., Westmore, B., 2014. Policy Challenges for the Next 50 Years. OECD Economic Policy Papers, No. 9, July 2014.

[5] The strong methodological differences between neoclassical and post-Keynesian approaches make a more detailed comparison difficult. The OECD estimates are based on potential output (with full employment). Nominal rigidities slow down the process of convergence, but by assumption, the system tends to absorb disequilibrium in four-five years.

[6] Although labour productivity is endogenous in the model, we consider the possibility of an additional exogenous – or unexplained – rate of growth of labour productivity.

Modelling technical progress as labour-saving or energy-saving

The EUROGREEN model assumes that firms face a choice between directing investment in new capital goods mainly towards the improvement of either energy efficiency or labour productivity. Although both the objectives can be pursued simultaneously to some extent, we assume that an increase (reduction) in the ratio between the cost of energy and the cost of labour generates a bias towards energy-saving (labour-saving) innovations embodied in new capital goods. This hypothesis allows us to investigate the link between changes in the relative cost of the production factors and their demand. For instance, a positive rate of growth in the oil price reduces GDP growth (w.r.t. the baseline scenario with a constant oil price), but leads firms to increase energy efficiency rather than labour productivity. However, the reduction in the rate of unemployment is a short-run effect. In the long run, the reduction of the demand, due to the fall in incomes and purchasing power, tends to more than offset this outcome, so that the rate of unemployment eventually becomes higher than it would have been without any increase in the oil price.

Can Working Time Reduction increase employment in post-growth economies?

In a post-growth society, population growth and labour productivity growth exacerbate the problem of unemployment. Low or zero GDP growth rates make it difficult to sustain an increase in employment, due to the stagnation of aggregate demand (i.e., both consumption and investment are expected to fall). On the other hand, the government has fewer resources to strengthen unemployment benefits, which would slow down the decline of consumption. In this context, WTR has been suggested as a remedy against high structural unemployment. We explore two alternative scenarios with a yearly reduction of 0.5% in average annual working hours over a period of ten years. The difference between the two scenarios is the presence or absence of wage moderation as an element of the working time reform. Both scenarios suggest that, without any other policy, in the short run there will be a contraction of the rate of growth associated with a decrease in the level of unemployment, and a decline in the profit share of income. The presence of an exogenous increase in labour productivity mitigates those effects. However, the positive effect on employment is offset – although not entirely – as soon as the direct effect of the policy stops (Figure S.2). The main intuition is that WTR increases the average cost of labour – even in the wage moderation case, due to the decline in unemployment – and spurs firms to invest strongly in labour saving technical progress, partly neutralizing the direct effect.

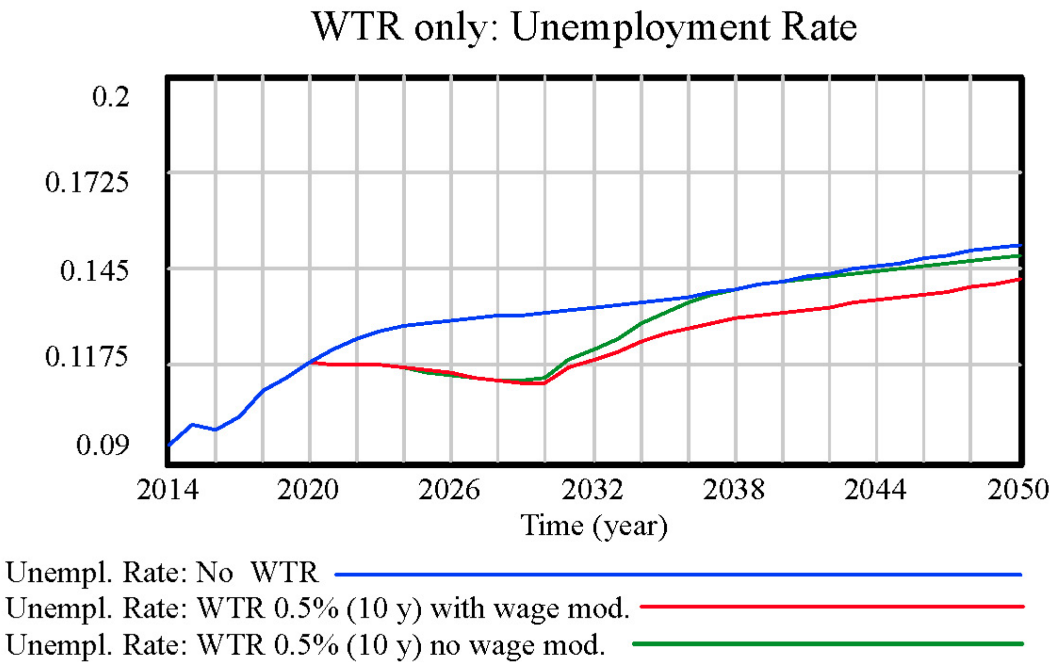

Figure S.2. Effect on the rate of unemployment of lowering average working hours by 0.5% per year from 2020 to 2030, assuming an exogenous labour productivity growth of 0.5% (y-axis scale: 0.1 = 10%). The blue curve shows the unemployment rate with no WTR policy (baseline scenario); the red curve shows the unemployment rate under WTR policy without wage moderation; the green curve shows the unemployment rate under WTR policy with wage moderation.

Can Regulating Energy Tax policy have an expansive effect?

There is a growing body of literature that analyses the expansive impact of Regulating Energy Taxes (RET) on GDP.[7] In accordance with this literature, the EUROGREEN model shows that a slight increase in the tax rate for the energy sector is able to generate a positive effect on aggregate income if the additional tax revenues from non-renewable energy are used to subsidize an increase in the production of renewable energy. We made a quite conservative hypothesis in terms of job creation, i.e., we assume that direct additional workers are involved only in the production of capital goods used in the

[7] See, for instance, Ekins, P., Speck, S., 2011. *Environmental Tax Reform (ETR): A Policy for Green Growth*. Oxford University Press, Oxford.

renewable energy sector. However, we assume that the flow of renewable energy is a public good that is distributed to the households. Thus, households receive a subsidy, which directly reduces the consumption of non-renewable energy and generates an increase in disposable income. This latter change increases the consumption of the three final goods and provokes a minor rebound effect on energy consumption. As a consequence the non-renewable energy sector shrinks, while GDP grows slightly faster than in the baseline scenario. In the simulation, we explore two policies under the exogenous increase in labour productivity for 0.5% per year: i) an increase in the tax rate from 10 to 13% on the traditional energy sector in one year, and ii) an increase in the tax rate from 10 to 14% in eight years. The increase in the energy tax rate leads to an increase in the cost of energy and this, in turn, reduces the automation rate (i.e., the rate of labour saving technical progress). This effect on the energy-labour cost ratio brings about a reduction in unemployment with respect to the baseline scenario (Figure S.3). On the other hand, the presence of exogenous labour productivity growth is necessary to avoid instability and large cyclical pathways.

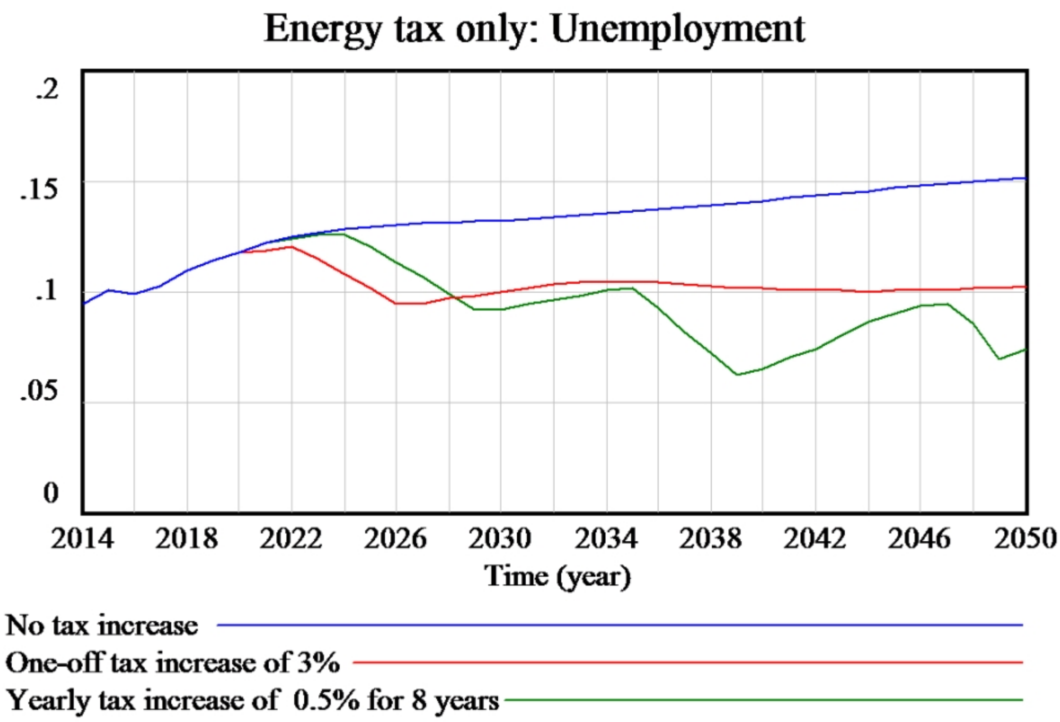

Figure S.3. Effect on the rate of unemployment of either a one-off energy tax rate increase of 3 percentage points (i.e., from 10% to 13%) or an increase of 0.5 percentage points per annum over 8 years (i.e., from 10% to 14%), with an exogenous labour productivity growth of 0.5% (y-axis scale: 0.1 = 10%).

Is there any complementarity between WTR and RET policies? Could they help define a sustainable policy mix?

The two policies described above call for an investigation of their combined effects. We consider the effect of WTR policies (without full wage moderation) together with an increase in the tax rate in the energy sector from 10 to 14% in eight years, and we compare this result to the baseline scenario (in both cases labour productivity growth is absent). This combination is able to significantly reduce unemployment even in the long run (Figure S.4), to reduce the public deficit (Figure S.5), to slightly reduce the profit share and inequality (Figure S.6), and to allow for a very low but positive rate of growth (Figure S.7). These results suggest that WTR and RET policies might exhibit strong complementarity since the increase in the cost of energy compensates for the increase in labour costs by promoting a balance in the investment decisions between labour saving and energy saving technical progress. At the same time, the positive effect on disposable income (generated by RET) can sustain aggregate demand and prevent a major fall of profits.

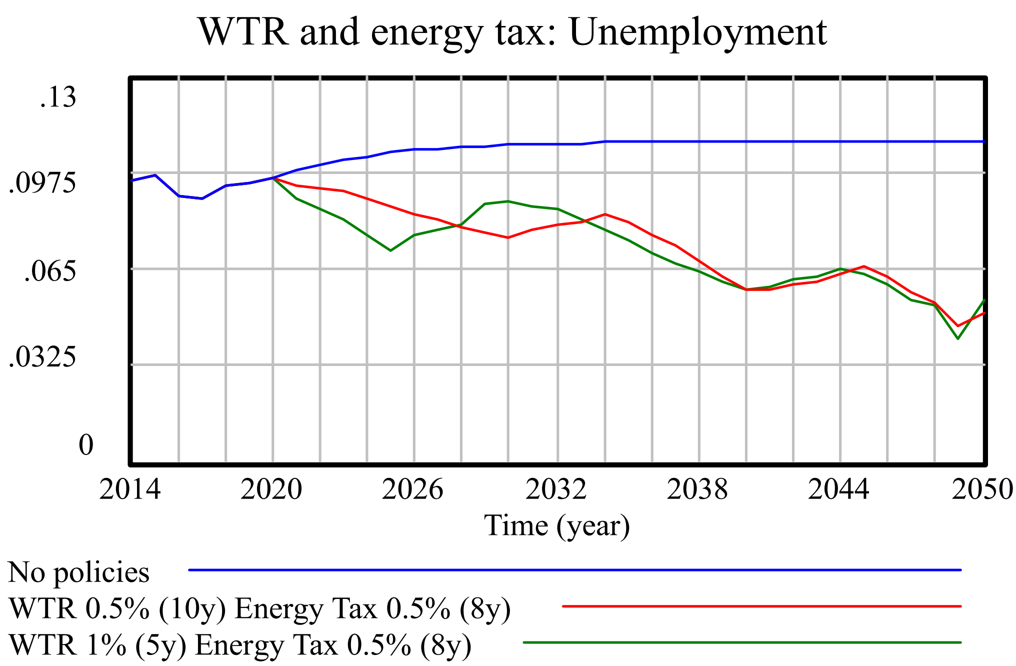

Figure S.4. Effect on the rate of unemployment of an energy tax rate increase of 0.5 percentage points per annum over 8 years (i.e., from 10% to 14%), together with either (red line) a reduction of working hours by 0.5% per year over 10 years, or (green line) by 1% per year over 5 years. No exogenous labour productivity growth. Y-axis scale: 0.1 = 10%.

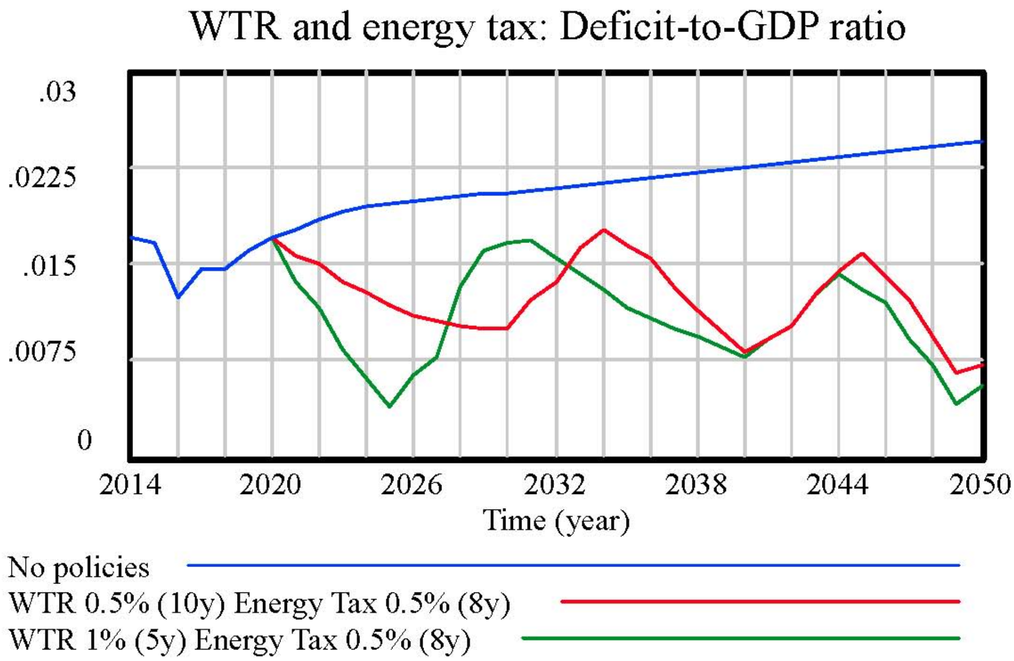

Figure S.5. Deficit-to-GDP ratio for the same scenarios as Figure S.4. Y-axis scale: 0.1 = 10%.

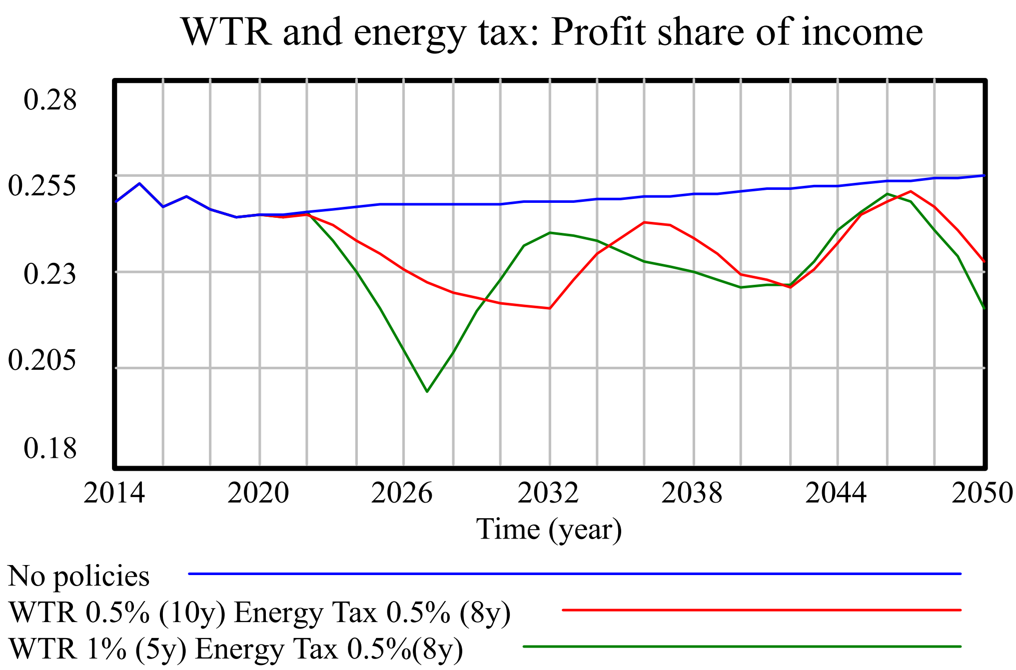

Figure S.6. Profit share of income for the same scenarios as Figure S.4. Y-axis scale: 0.1 = 10%.

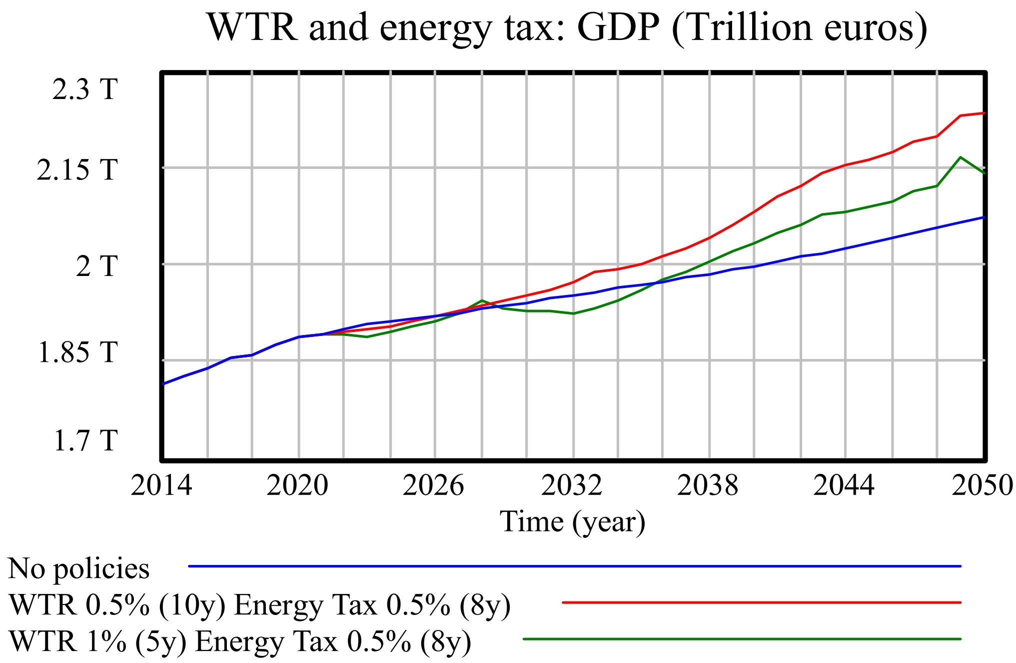

Figure S.7. GDP (trillion euros in constant prices) for the same scenarios as Figure S.4.

None of the simulations presented here should be interpreted as an attempt to *predict* what particular future is most likely to come to pass. Instead, the simulation results represent a range of possible futures, or internally consistent scenarios, the likelihood of which depends on the robustness of the underlying assumptions (e.g., theoretical relationships that determine the structure of the model, parameter values of behavioural equations, etc.). EUROGREEN is work in progress, so the results of the present version should be handled with great caution. Future work will make it possible to compare the results more closely to the projections of official bodies or academic researchers, concerning, for instance, industrial automation trends and their effects, the evolution of energy efficiency, and the future of the welfare state.

1. Introduction

The increasing general awareness of the accelerating deterioration of the global environment, together with a growing body of evidence on the close links between economic growth and environmental impacts,[8] are making the provision of coherent alternatives to 'growthism' an ever more urgent task. Among the efforts to contribute to this task is the ongoing development of an ecological macroeconomics; a theoretical and methodological framework for analysing the economy as a subsystem of the biosphere.[9] To a large extent, the development of ecological macroeconomics draws upon an ongoing convergence between post-Keynesian and ecological economics. Until recently, post-Keynesian economics rarely paid attention to environmental issues, and ecological economics strongly favoured microeconomic themes over macroeconomics, which is the level of analysis of most post-Keynesian economics. This is now changing, as latent synergies are exploited for the development of ecological macroeconomics. The EUROGREEN model is part of this field, drawing upon works such as Dafermos et al. (2015; 2016), Godin (2013; 2014), and Naqvi (2015). The model also shares the system dynamics approach of ecological macroeconomic models such as Bernardo and D'Alessandro (2016), and Jackson and Victor (2015). System dynamics is a suitable tool for the analysis of complex systems. It has a high degree of flexibility and a graphical structure which facilitates the identification of feedback mechanisms (Costanza and Ruth 1998; Costanza et al. 1993). Finally, EUROGREEN can also be characterized as a post-Keynesian stock-flow consistent model (PK-SFC).[10]

'Stock-flow consistency' denotes an accounting framework that lends logical consistency to the macroeconomic accounting for stocks and flows, eliminating the 'black holes' that are common in mainstream and earlier post-Keynesian models.[11] Interest in stock-flow consistent modelling has risen strongly since the 2008 financial crisis, as "a credit-cum-debt crisis followed by recession" was predicted nearly

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[8] See e.g. Antal and van den Bergh (2014); Hall and Klitgaard (2012); Smil (2014); Victor (2010).

[9] Pioneering works in this field include Jackson (2009) and Victor (2008).

[10] A caveat is required here. The current version of the model is not entirely stock-flow consistent, as it includes oil imports, giving rise to a flow of payments that does not accumulate to a stock, but instead represents a monetary drain on the economy. We intend to make a later version of the model fully stock-flow consistent.

[11] See Appendix 1 for a description of the model's balance sheet and transactions-flow matrices, which are fundamental components of the SFC accounting framework.

exclusively by economists who used such non-mainstream 'accounting' or flow-of-funds models (Bezemer 2010). [12] According to Godley and Lavoie (2007: 384), "[t]he main purpose of having a formal model, based on transactions accounts which have no black holes, is that one is forced to consider how each part of an economy is interconnected with every other part". The SFC accounting framework is complemented by a set of equations describing the behaviour of economic actors. The behavioural assumptions of EUROGREEN are mainly based on post-Keynesian economic theory, making it a PK-SFC model.[13] PK-SFC models are built around collective actors (institutional sectors); typically households, non-financial firms, banks, the government, and the central bank. Stock-flow consistency is guaranteed by the imposition of 'budget constraints' on individual sectors and on the economy as a whole (net financial assets must sum to zero).

EUROGREEN is, however, an atypical PK-SFC model for two related reasons. First, we do not lend the usual primacy to the integration of financial stocks and flows with the 'real' economy of goods and services, but focus mainly on the integration of the economy with natural resources and environmental sinks.[14] Second, we combine post-Keynesian theories of demand-led economic growth with supply-side issues such as labour and resource productivity, which post-Keynesian economics has hitherto largely neglected. It is in this sense that EUROGREEN joins in the efforts of developing an ecological macroeconomics.

[12] The main PK-SFC textbook is Godley and Lavoie (2007). A recent review of the field is Caverzasi and Godin (2015).
[13] For an advanced textbook on post-Keynesian economics, see Lavoie (2014).
[14] In the present version of the model, households hold a single financial asset (bank deposits), and household debt is not modelled.

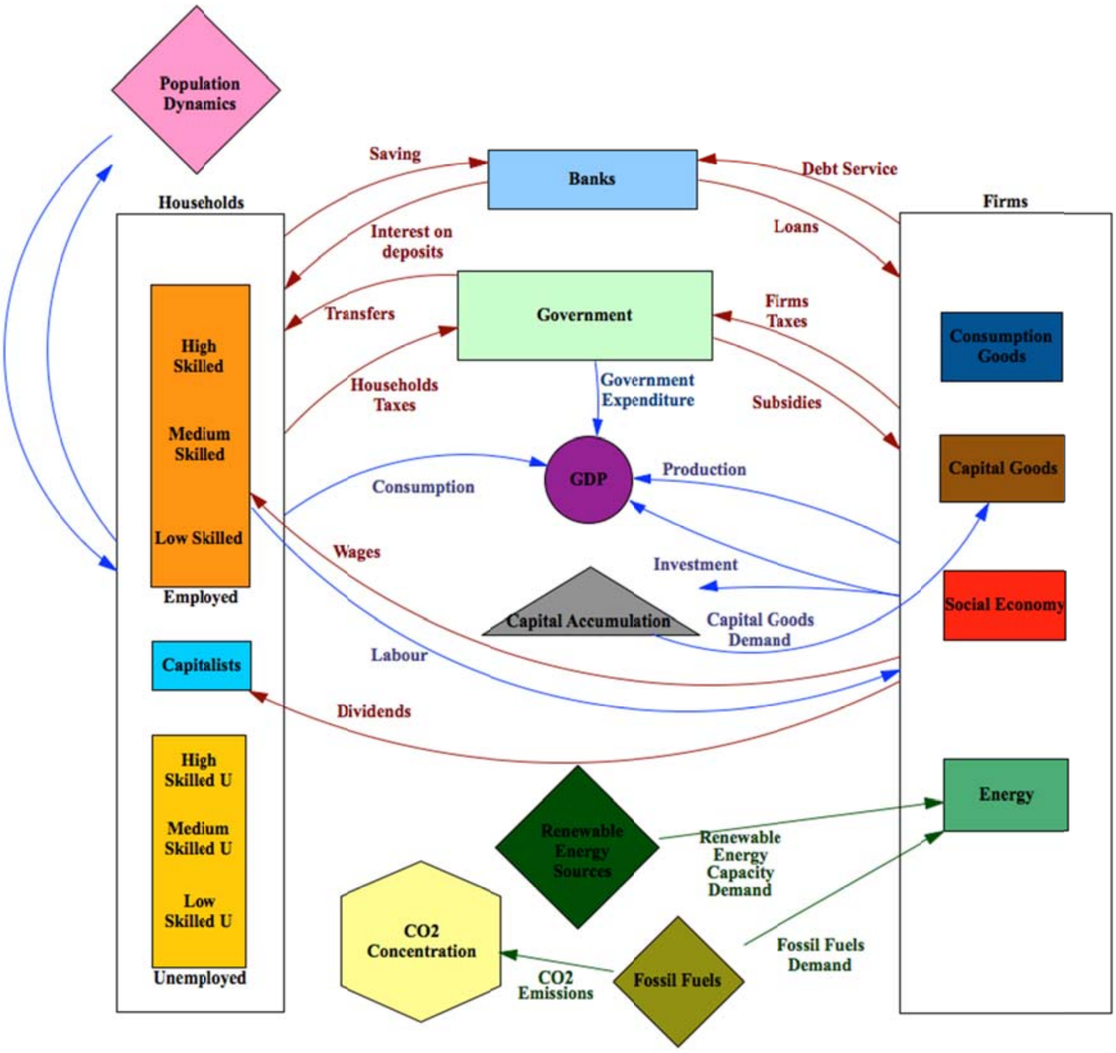

Figure 1. High-level structure of the EUROGREEN model.

An overview of the model is given in Figure 1. A notable feature is the subdivision of the household sector into seven categories. This division is made to allow a more detailed analysis of income distribution, going beyond the customary post-Keynesian division of households into capitalists and wage-earners. Almost as novel is the subdivision of the firms sector – usually treated as a single entity in post-Keynesian models – into four different industries: a consumption goods and services sector (for final consumption), a capital good sector (intermediate consumption), a social economy sector, and an energy sector. Our addition of a social economy sector is motivated by our interest in its potential role in sustainability transitions.

2. Population dynamics, household categories, income distribution, and consumer behaviour[15]

The EUROGREEN population dynamics are based on the World3 model (Meadows et al. 2004). There are four age groups: 0-14, 15-44, 45-64, and 65 years and above. Each cohort is associated with a specific mortality rate. The population model also includes assumptions about fertility, reproductive lifetime, life expectancy, and the skill composition of each age group. Except for the skill composition, these parameters are all treated as fixed throughout the simulations. The labour force is constituted by the two middle cohorts, and we assume a fixed labour participation rate out of the two cohorts. This means that the labour force participation rate (% of total population ages 15+) is in 2016 at 57% (very close to the ILO's estimates). In future versions of EUROGREEN, the population model will be more closely calibrated to empirical data, and will incorporate assumptions from The 2015 Ageing Report (European Commission 2014). The population model is an essential element for analysing the challenges that an ageing population poses to the welfare state. However, this issue has not been analysed by the current model, and requires us to incorporate an active economic role for the retired population. In the current version, the modelling of household activity centres on the working-age population, which is the focus of the rest of this section.

Macroeconomic models in the tradition of Michal Kalecki (1971; 2009 [1954]) pay attention to the effect of income distribution on the aggregate demand for final goods and services in the economy. The basic assumption is that workers consume a larger share of their income than capitalists (i.e., workers save less), so that a more progressive distribution of income raises the aggregate demand. The EUROGREEN model includes this worker/capitalist distinction in order to address the so-called functional distribution of income. In addition, the model also addresses the so-called personal distribution of income by subdividing workers into three main categories: low-skilled, medium-skilled, and high-skilled. These categories correspond to OECD usage in terms of educational attainment (respectively: lower secondary level or less, upper secondary and tertiary). We also distinguish between employed and unemployed workers, the assumption being that the latter consume a higher proportion of their income and wealth.

[15] See Appendix 2 for a technical description of these aspects of the model.

All households in each group are assumed equal. We assume that each household has only one income provider, working full-time in one of four industries (see section 3 on the industrial sectors, and section 4 for the determination of the level of employment).[16] The banking, government, and renewable energy sectors do not employ any workers.[17] The wage bill from each industry is the main source of income of employed worker households, and also a source of income taxes for the government sector, following a progressive tax schedule.[18] The share of income not consumed within a modelling period is saved by definition, and the flow of saving accumulates into a stock of wealth held – in the case of workers – exclusively as bank deposits, which is the only monetary asset as there is no cash.[19] The number of households of unemployed workers is determined as the difference between the labour force and the number of employed. All unemployed households receive a benefit determined as a proportion of the lowest skill-specific wage across all industries, thus avoiding any unrealistic rise in earnings as a household moves from employment to unemployment. The disposable income of capitalist households is the sum of distributed profits net of dividend taxes, plus interest rate earnings on deposits. The wealth of capitalists is composed of bank deposits plus the net worth of firms, which are assumed to be privately owned; there is no stock market in the model.

The amount of goods and services consumed by each household over a modelling period (i.e., one year) is determined by its expected disposable income and wealth, as well as its propensity to consume rather than save.[20] That is, households decide how

[16] This conventional assumption, together with the assumption that all work is full-time, means that the model is not able to address powerful feminist arguments for Working Time Reduction (WTR). Real-world households are often composed of a male full-time worker and a relatively underpaid female part-time worker. WTR would allow a more equal distribution of unpaid domestic work and – perhaps combined with a legislated right to full-time employment – could gain more economic independence for women. Moreover, the scope for WTR, in the face of a growing dependency ratio, is arguably improved by the prospect that WTR allows many part-time workers to move on to full-time employment.

[17] We intend to include employment in the renewable energy sector in a later version of the model.

[18] We use data from the EU KLEMS database to obtain average wages for each skill category for our sectors.

[19] In other words, the model belongs to the category of 'pure credit economy' models. It can be modified to include cash as well as other financial assets, but this would require the inclusion of (empirically estimated) behavioural equations determining portfolio choice, which we leave for future research.

[20] This Modigliani consumption function implies that households aim to achieve a certain target ratio between their stock of wealth and their flow of income (Godley and Lavoie 2007: 75).

much to consume over the year in relation to their expected rather than actual income for that year. We assume that households expect their income to be equal to their realized income of the previous year.

As mentioned above, we assume that all wage-earner households have higher propensities to consume than capitalist households. We also assume that all unemployed workers have a higher propensity to consume than any employed worker. Finally, we assume that low-skilled workers have a higher propensity to consume than medium-skilled workers, who in turn have a higher propensity to consume than high-skilled workers. However, the current calibration of the model has only allowed these assumptions to be respected for the propensity to consume out of income, not for the propensity to consume out of wealth (see Table 1). This shortcoming is largely due to inconsistencies in the allocation of deposits across household groups. We intend to remedy this in a later version of the model. We also intend to undertake further empirical verification of these assumptions.

Household consumption is allocated across three sectors: the consumption goods and services sector, the social economy, and the energy sector. Each sector may be thought of as producing only one type of good with a single price. The consumption mix is determined by consumer preferences, which are fixed, and by the relative prices of the three goods.

	Unemployed low-skilled	Unemployed medium-skilled	Unemployed high-skilled	Employed low-skilled	Employed medium-skilled	Employed high-skilled	Capitalists
Propensity to consume out of income	0.95	0.9	0.9	0.86	0.81	0.75	0.73
Propensity to consume out of wealth	0.025	0.06	0.035	0.065	0.007	0.098	0.05

Table 1. Parameter values for the propensities to consume out of income and wealth in the current model calibration.

3. Modelling of production

The productive sector is divided into four industries: consumption goods and services, social economy, capital goods, and energy. We use empirical data to calculate the initial values of the stocks and ratios of our custom-defined industries.[21] The main sources of data related to production are the INSEE (French national statistics office) *Macro-economic database* and the *EU KLEMS Growth and Productivity Accounts*. Table 2 shows how the industries are superposed on the empirical data following the NACE Rev. 2 classification (the consumption goods and services sector and the capital goods sector share some empirical characteristics of *Total manufacturing* and *Construction*).

The manufacturing sector (C) is subdivided into five components in accordance with the INSEE A17 level, and allocated across EUROGREEN sectors (with overlaps). After the analysis of French INSEE data on Gross Value Added and Net Fixed Assets, and the calculation of capital productivities, the sectors L (real estate activities) and O (public administration) are excluded, since their large capital stocks and low capital productivity would otherwise dominate the sectoral characterization. Output and capital stock data are not available from INSEE for NACE sectors T (activities of households) or U (activities of extraterritorial organizations), so these sectors are not included in the current version of the model.

In line with post-Keynesian economics, output is primarily determined by the effective demand for final and intermediate goods and services (see Setterfield 2002 for an overview of theories of demand-led economic growth). However, output is also constrained by the size and skill composition of the labour force.

Energy is both an intermediate and a final good, consumed by all industries except (for now) the energy sector itself, as well as by households and the government. Industrial energy consumption is a function of actual output and the energy efficiency of the capital stock.[22]

[21] In some scenarios, we have also included a separate renewable energy sector. However, the modelling of this sector is not based on empirical data.

[22] In the current calibration of the model, industrial energy consumption ranges from just 6% to 1% of final energy consumption of all sectors (households, government, and industry). This is an unrealistically small share, and means that our modelling of an energy transition, which

Sector	NACE Rev. 2 description	NACE Rev. 2 code
Consumption goods and services	Agriculture, forestry and fishing	A
	Manufacture of food, beverages and tobacco	C1
	Manufacture of electrical, electronic and computer equipment; Manufacture of machinery	C3
	Manufacture of transport equipment	C4
	Manufacture of other industrial products	C5
	Construction	F
	Wholesale and retail trade, repair of motor vehicles and motorcycles	G
	Transportation and storage	H
	Accommodation and food service activities	I
	Information and communication	J
	Financial and insurance activities	K
	Professional, scientific and technical activities	M
	Administrative and support service activities	N
Social economy	Education	P
	Health	Q
	Arts	R
	Other Service Activities	S
Capital goods	Manufacture of electrical, electronic and computer equipment; Manufacture of machinery	C3
	Manufacture of transport equipment	C4
	Construction	F
Energy	Manufacture of coke and refined petroleum products	C2
	Electricity, gas and water supply	D+E

Table 2. Sectoral superposition on the NACE Rev. 2 industrial classification.

focuses largely on the industrial sector, has a smaller impact on total energy use than it would have with a more realistic calibration. Remedying this shortcoming is a priority of future work on the model.

3.1. Modelling private investment behaviour

Private investment decisions are at the core of the model dynamics. The two principal decisions modelled concern the amount and type of business investment in fixed capital.[23] The amount of investment is determined by the level of utilization of fixed capital and the expected profitability of capital. Firms finance their investment firstly out of retained earnings. Whenever their planned investment exceeds retained earnings, firms borrow the difference from private banks. If investment is smaller than retained earnings in any given period, firms will use the surplus to reduce their stock of bank loans.

Regarding the type of investment, the model focuses on firms' choice between investing in mainly labour-saving or energy-saving technology. The choice to install labour-saving fixed capital (i.e., automating production) is here referred to as 'grey' investment, and the choice to install the most energy-saving technology available is called 'green' investment. The simulations performed with the model thus far have assumed an inverse relationship between the *changes* in the rates of growth of labour productivity and energy efficiency.[24] For example, if there is a shift from grey to green

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[23] The model does not address financial investment or financialization, which is the focus of a large number of recent post-Keynesian models.

[24] Taylor (2008:3) finds "a robust relationship between increasing energy use per worker and labor productivity growth" when analysing empirical data for both developing and rich countries for the periods 1970-1990 and 1990-2004. This means that labour productivity and energy efficiency do not tend to move in step, as shown by the identity:

$$\frac{\text{Output}}{\text{Number of workers}} = \frac{\text{Output}}{\text{Energy consumed}} \times \frac{\text{Energy consumed}}{\text{Number of workers}}$$

which is equivalent to:

$$\text{Labour productivity} = \text{Energy efficiency} \times \text{Energy-labour ratio}$$

so that (using 'hats' to indicate rates of growth):

$$\widehat{\text{Labour productivity}} = \widehat{\text{Energy efficiency}} + \widehat{\text{Energy-labour ratio}}$$

Our assumption of an inverse relationship between the changes in the rates of growth of labour productivity and energy efficiency is compatible with the above-quoted finding, although somewhat more technologically optimistic assumptions are also compatible. In future versions of the model, we wish to make a wider range of assumptions about the relationship between labour productivity and energy efficiency, and associate the assumptions with different investment, the rate of growth of energy efficiency increases, whereas the rate of growth of labour productivity decreases. However, we have made quite optimistic assumptions about energy efficiency, so that its rate of growth is always positive (although less so for grey investment). In contrast, the rate of growth of labour productivity can be negative at times. In the current version of the model, firms choose grey (labour-saving) investment when the price of energy has declined relative to the average wage in the previous period, so that energy has become a relatively cheaper input than labour. Conversely, firms choose green (energy-saving) investment when energy has become relatively dearer. We plan to adopt a more realistic decision rule in future versions of the model, using the cost share of each factor (i.e., price times quantity) instead of the price of one unit of each factor.

Let us illustrate the short-run model dynamics associated with the green or grey investment decision, anticipating some of the mechanisms explained in later sections. Figure 2 shows a causal loop diagram with two feedback loops; the top one is a reinforcing (positive) loop, and the bottom one is a balancing (negative) loop. We may, for example, start from labour productivity, and assume that there has been a fall in the rate of growth of this variable. If we trace the top loop, which goes straight from labour productivity to wages, we see that lower productivity growth causes lower wages (the plus-sign at the head of the connecting arrow indicates that the two variables move in the same direction, whereas a minus-sign means movement in opposite directions). Lower wages, in turn, increase firms' bias toward green investment, which again reduces the rate of growth of labour productivity, so that the loop is reinforcing. Along the bottom loop, starting again with a fall in the rate of growth of labour productivity, we see that this leads to higher employment, which raises wages, so that the bias toward green investment is reduced, which now raises the rate of growth of labour productivity, balancing the initial fall.

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narratives about technological possibilities. Furthermore, we wish to bring out the relationships between labour productivity and energy efficiency more clearly in the structure and presentation of the model. A key goal of a low-carbon transition with full employment is to reduce energy consumption while creating employment; in other words, to lower the energy-labour ratio. As shown by the above identities, this objective is tied up with the relationship between labour productivity and energy efficiency.

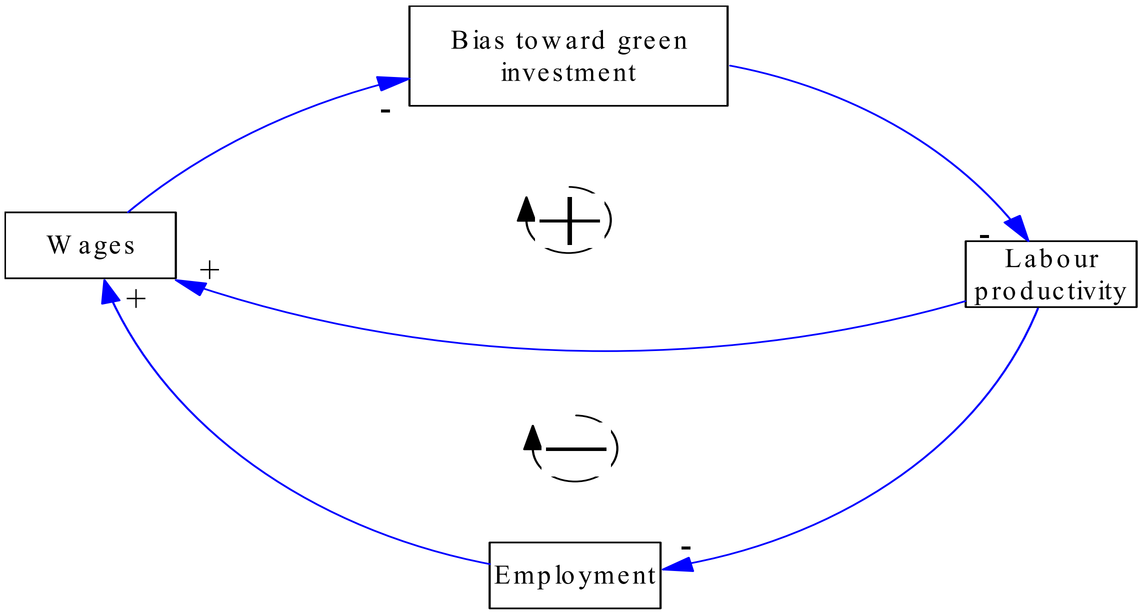

Figure 2. Green vs. grey investment: Feedback loops via labour productivity.

There are hundreds of ways in which a given variable may affect other variables in the model, giving rise to loops that go all the way to the original variable. The loops shown here are, however, among the shortest and most important ones. Since we have now seen some feedback loops associated with the impact of the green/grey investment decision on labour productivity, let us also view an example involving its impact on energy efficiency (Figure 3). We may start by assuming that there has been an increase in the rate of growth of energy efficiency. This produces a fall in the energy consumption of firms. This, in turn, causes production costs and prices to fall, so that consumption rises.[25] There is a consumption-driven boost to output, which increases employment and wages, leading to a reduction of the bias toward green investment in favour of labour-saving investment. This lowers the rate of growth of energy efficiency, so that what we get is a balancing loop.

[25] The treatment of production costs and product prices is explained in sections A3.6 and A3.7 of Appendix 3.

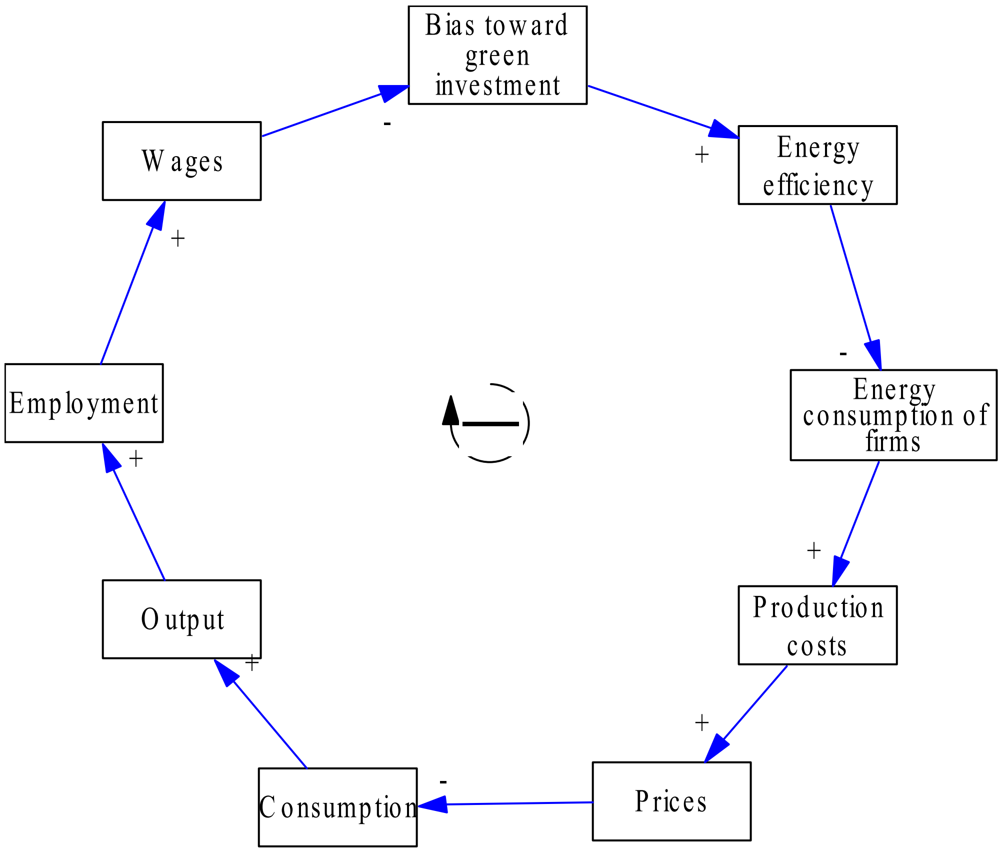

Figure 3. Green vs. grey investment: Feedback loop via energy efficiency.

4. Employment, labour productivity, wages, and working time

In post-Keynesian models, the level of employment is usually determined as the ratio between current output and labour productivity. Most post-Keynesian models treat employed workers as a single, homogeneous group. However, some models include a distinction between 'fixed' and 'variable' labour (e.g., Lavoie 2009; Dafermos and Papatheodorou 2015), and this is the approach followed here. The employment of fixed labour is determined in relation to potential output (i.e., output at full capacity utilization, determined by the size of the capital stock), which typically varies more slowly than the actual level of output, hence the label 'fixed'.[26] The amount of variable labour, however, is determined as usual in relation to current output (i.e., the degree of capacity utilization). We assume that high-skilled workers are fixed labour, and that medium and low-skilled workers are the more cyclical, variable labour.[27] The proportion of high-skilled employees among all employees at full capacity operation is constant through time, and the proportion of medium-skilled to low-skilled employees is always constant, irrespective of the degree of capacity utilization.[28] The skill composition is sector specific, and has been calculated from the EU KLEMS database using data for the year 2008. In sum, the level of employment depends on potential output, actual output, labour productivity, and skill composition. The skill composition can be seen as given by the technical requirements of production, with complementarity between skill levels. Our approach takes the level of employment to be determined by employers, since they are the ones who decide how much to produce and invest. The notion of labour supply, including employees' decisions concerning the trade-off between the amount of work and leisure time, is not considered in the model. Given the existing power relations between employers and employees, this is arguably not a serious omission, but it does mean that the model cannot address voluntary downshifting behaviour.

The hourly productivity of labour is specific to each industry, and its initial magnitude is calculated using empirical data. The evolution of labour productivity depends in part,

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[26] See Appendix 4 for technical details.

[27] The status of medium-skilled workers is subject to change on a country-by-country basis, depending on the outcome of the data analysis.

[28] In future versions of the model, we plan to make the skill composition of the employed workforce subject to demographic trends independent of the degree of capacity utilization.

as discussed above, on firms' choice between green or grey investment. In addition, it also depends on the rate of growth of the average real wage of the corresponding industrial sector, in line with the 'efficiency wage' theory, according to which a higher wage motivates workers to become more productive. Furthermore, labour productivity is negatively related to the change in working hours, so that, for instance, a 10% reduction in working time will cause labour productivity to increase, although by a lesser percentage.[29] The model does not distinguish between standard or actual hours of work, so the WTR gains in productivity can be viewed both as the result of less worker fatigue (associated with lower actual hours), and increased rationalization of the productive process or higher standard intensity of work imposed by employers (associated with lower standard hours). Finally, the model includes an 'unexplained' rate of productivity growth, which is set – depending on the scenario – at 0.5%, 0.3% or 0% per annum.

In the baseline scenario, annual nominal wages for all skill levels are assumed to depend positively on the rate of growth of labour productivity (in accordance with real-world collective bargaining), and negatively on the rate of growth of unemployment. We aim to use the model to combine WTR policy with various forms of wage moderation. In the simulations conducted so far, we have defined wage moderation as the absence of any negotiated rise in the hourly wage in connection with the implementation of the reform. This means that the annual wage is reduced, although the positive impact of labour productivity growth on wages remains. In the scenarios without wage moderation, the hourly wage rises in proportion to the reduction in working time, and is also boosted by rises in productivity. In our future work, we plan to include wage moderation scenarios that are more consistent with historical experience, defining wage moderation as the preservation of the annual wage (i.e., a proportional rise in the hourly wage) but no further increase in wages based on productivity growth for a certain time. In particular, we wish to analyse the effects on income distribution of assuming wage moderation for high-skilled workers only.[30] In future versions of the model, we also intend to treat the

[29] The quantification of the impact of WTR on labour productivity is very important when modelling WTR policies, but also very uncertain. In the current calibration, we have assumed that 20% of any reduction in hours is translated into gains in productivity.

[30] In the case of France, "[i]n the vast majority of cases, the 35-hour week came without loss in pay", although some workers did earn less because they worked less overtime (Hayden 2006: 518). Moreover, "[w]age moderation was easier to accept for more affluent employees, who

impacts of labour productivity growth and WTR on wages more realistically as a coordinated whole, rather than as separate effects, since they are both part of the same bargaining process.

were more likely before the change to feel a pressing need for extra time rather than money" (ibid.: 529).

5. Banking and government sectors

Banks have a passive role in the model. They extend any credit demanded by firms, and they buy any public debt that the government wishes to sell. Banks' assets are business loans and government bonds (households are assumed not to borrow), and their liabilities are household deposits. All interest rates are determined exogenously (i.e., outside the model). We assume that banks distribute all their profits to capitalist households, and therefore have no net worth.

The government also has a passive role in the model, apart from the model user's external modification of tax rates and other policy levers. Public consumption expenditures are determined as a fixed multiple of the aggregate consumption expenditure of the seven household sectors. The allocation of government consumption across the goods and services sector, the social economy, and the energy sector, simply mirrors that of households. Apart from public consumption, there are only two other forms of government expenditure in the current version of the model; unemployment benefit transfers and interest payments on the public debt. The government funds its deficit by selling a single type of bonds. We assume that all government debt is held by private banks, thus avoiding the modelling of households' portfolio choice. The model could quite easily be extended to include alternative fiscal policies, such as countercyclical spending, deficit-to-GDP limits, or subsidies to industrial sectors that adopt work-sharing policies.

6. Conclusion to part II

The EUROGREEN model is being developed to provide a concrete understanding of some important policy challenges associated with the transition to ecologically sustainable and socially equitable post-growth societies in the European Union. The model aims to test, in a formal setting, the effectiveness and coherence of Green economic policies, to support the creation of widely attractive narratives about possible futures. The focus lies on a subset of challenges for attaining the overall goal of sustainable prosperity, namely full employment (or – more broadly – decent livelihoods), low inequality, fiscal sustainability, and a sustainable energy system. The purpose is not to *predict* what particular future is most likely to occur, but to present internally consistent scenarios representing alternative futures, the feasibility of which will depend on the robustness of the underlying assumptions.

EUROGREEN is work in progress, so the results of the present version should be handled with great caution. The simulations suggest that Working Time Reduction (WTR) strongly reduces unemployment in the short run, but has a weaker – yet still positive – effect in the long run. An increase in the Regulating Energy Tax (RET) rate also has a desirable impact on unemployment, but the best outcome is achieved by combining the two policies, which has synergistic rather than merely additive effects. Future work will make it possible to compare the results more closely to the projections of official bodies or academic researchers, concerning, for instance, industrial automation trends and their effects, the evolution of energy efficiency, and the future of the welfare state.

Appendix 1: Technical appendix to section 1

This appendix describes two matrices that are essential to any stock-flow consistent (SFC) model; the balance sheet matrix and the transactions-flow matrix. The balance sheet matrix of EUROGREEN is shown in Table A1.1.

	W	CA	Sector C	Sector S	Sector K	Sector E	Bank	Govt	∑
Money deposits	D_W	D_{CA}					-D		0
Loans			$-L_C$	$-L_S$	$-L_K$	$-L_E$	$\sum L_i$		0
Bonds							B	-B	0
Fixed capital			K_C	K_S	K_K	K_E			$\sum K_i$
Owned firms		$\sum NW_i$	$-NW_C$	$-NW_S$	$-NW_K$	$-NW_E$			0
Balance (net worth)	$-D_W$	-V						B	$-\sum K_i$
∑	0	0	0	0	0	0	0	0	0

Table A1.1. Balance sheet matrix of the EUROGREEN model.

Each column represents an institutional sector. The balance sheet structure of all worker groups is the same, so to save space, they are displayed in a single column (W). The column to its right represents capitalist households (CA), followed by the four industries (C for consumption goods and services, S for social economy, K for capital goods, and E for energy). The private bank and government sectors complete the sectoral structure of the model. The balance sheet matrix shows all the macroeconomic stocks of the model in nominal monetary terms. The stocks are the bank deposits (D) held by households, the bank loans (L) borrowed by firms, the government debt (B) – held in its entirety by private banks, the fixed capital of firms (K), the net worth of firms (NW), and the total wealth of capitalist households (V). Firms are assumed to be privately owned by capitalists; there are no equities and no stock market.

EUROGREEN uses discrete time, and the values in the matrix refer to the end of the current period, following the notational conventions of Godley and Lavoie (2007: 60-61). Further on, we will encounter variables with time subscripts, usually -1 which refers to the value at the end of the previous period. This is the same as the value at the beginning of the next period. Each row of the balance sheet matrix represents an asset class. All stocks, except for fixed capital, are *financial* assets and liabilities. Because net financial assets sum to zero, the net worth of the economy is equal to the monetary value of the only 'real' asset in the model; fixed capital. All liabilities, including net worth, carry a minus sign; assets carry an implicit plus sign.

The transactions-flow matrix (Table A1.2) registers all the transactions that take place within a time period. In the main area of the matrix, each row represents a type of transaction, showing that all flows must come from somewhere and go somewhere, so that each row sums to zero. Each column shows the budget constraint of the actor. Here, we distinguish between employed workers (WE) and unemployed workers (WU), thus highlighting their distinct sources of income. Below the main area is the 'flow-of-funds' section, which shows the changes in stock variables from the beginning to the end of the period generated by the flows. In the transactions-flow matrix, variables with an implicit plus sign represent sources of funds, i.e., inflows. Variables preceded by a minus sign are uses of funds, or outflows. For the flow-of-funds variables, this notation is "strongly counter-intuitive since the *acquisition* of a financial asset that would *add* to the existing stock of asset, say, money, by the household sector, is described with a *negative* sign. But all is made clear so soon as one recalls that this acquisition of money balances constitutes an *outgoing* transaction flow, that is, a *use* of funds" (Godley and Lavoie 2007: 40). All productive sectors and the bank have a current account and a capital account. The current account of firms registers sales and production costs, and the capital account registers investment and how it is financed. The current account of the banking sector registers payments made or received, and the capital account registers changes in the stock of assets and liabilities. In the transactions-flow matrix, all rows and columns sum to zero. Capital gains have not been modelled.

Table A1.2. Transactions-flow matrix.

				C		S		K		E				
	WE	**WU**	**CA**	**Current**	**Capital**	**Current**	**Capital**	**Current**	**Capital**	**Current**	**Capital**	**Banks**	**Govt**	**Σ**
Consumption of C and S	$-C_{WE}^{c,s}$	$-C_{WU}^{c,s}$	$-C_{CA}^{c,s}$	Y_c		Y_s							$-C_{G}^{c,s}$	0
Energy	$-C_{WE}^{e}$	$-C_{WU}^{e}$	$-C_{CA}^{e}$	$-C_{c}^{e}$		$-C_{s}^{e}$		$-C_{k}^{e}$		Y_e			$-C_{G}^{e}$	0
Fixed investment					$-I_c$		$-I_s$	Y_k	$-I_k$		$-I_e$			0
Wages	$\sum W_i N_i$			$-\sum W_C N_C$		$-\sum W_S N_S$		$-\sum W_K N_K$		$-\sum W_E N_E$				0
Retained earnings				$-FU_c$	FU_c	$-FU_s$	FU_s	$-FU_k$	FU_k	$-FU_e$	FU_e			0
Dividends			$\sum FD_i$	$-FD_c$		$-FD_s$		$-FD_k$		$-FD_e$		$-FD_b$		0
Interest on loans				$-i_{l,-1}L_{c,-1}$		$-i_{l,-1}L_{s,-1}$		$-i_{l,-1}L_{k,-1}$		$-i_{l,-1}L_{e,-1}$		$i_{l,-1}L_{-1}$		0
Interest on deposits	$i_{d,-1}D_{WE,-1}$	$i_{d,-1}D_{WU,-1}$	$i_{d,-1}D_{CA,-1}$									$-i_{d,-1}D_{-1}$		0
Interest on bonds												$i_{b,-1}B_{-1}$	$-i_{b,-1}B_{-1}$	0
Unempl. benefit		UB											$-UB$	0
Taxes	$-T_{WE}$	$-T_{WU}$	$-T_{CA}$							$-T_e$			T	0
Δ loans					ΔL_C		ΔL_S		ΔL_K		ΔL_E	$-\sum \Delta L_i$		0
Δ deposits	$-\Delta D_{WE}$	$-\Delta D_{WU}$	$-\Delta D_{CA}$									ΔD		0
Δ bonds												$-\Delta B$	ΔB	0
Δ net worth	$-\Delta D_{WE}$	$-\Delta D_{WU}$	$-\Delta V$		ΔNW_C		ΔNW_S		ΔNW_K		ΔNW_E		ΔB	0
Σ	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 2: Technical appendix to section 2

A2.1. Households of wage earners

Variables referring to wage-earners carry the subindices L, M, and H to denote skill level (low-skilled, medium-skilled, and high-skilled), and the subindices E and U to denote employment status (employed, unemployed). The number of employed workers in each skill category is the sum of their employment in each industry (the determination of which is described in a later section):[31]

$$N_{jE} = N_{jE}^{c} + N_{jE}^{s} + N_{jE}^{k} + N_{jE}^{e} \ , \ \forall j \in \{L, M, H\} \tag{1}$$

The number of households of unemployed workers is determined as a residual, with N_j being the total number of households in the jth skill category:

$$N_{jU} = N_j - N_{jE} \tag{2}$$

The endogenous variables of the equations that follow typically refer to each household category as a whole, not to the individual household. The nominal[32] disposable income of employed workers (YD_{jE}) is their wage bill from each industry, net of income taxes, plus interest earnings on deposits (which are modelled as tax-exempt):

$$YD_{jE} = (1-\theta_j)\cdot\left(W_j^c N_{jE}^c + W_j^s N_{jE}^s + W_j^k N_{jE}^k + W_j^e N_{jE}^e\right) + i_{d,-1} D_{jE,-1} \tag{3}$$

where θ_j is the income tax rate specific to each level of income, and W_j^i is the nominal annual wage in the ith industry, which is multiplied by sectoral employment. We define

[31] In general for this manuscript, numbered equations are used in the computer model, whereas non-numbered equations are not.

[32] 'Nominal' variables are expressed in current prices, in contraposition to 'real' variables that represent the number of physical objects produced or consumed, or a monetary value corrected for inflation. In this manuscript, nominal variables are typically denoted by uppercase letters and real variables by lowercase letters.

the nominal unemployment benefit as a proportion *ub* of the lowest wage across all industries, within a certain skill-level:

$$UB_j = ub \cdot \min\left\{W_{j,-1}^{c},\, W_{j,-1}^{s},\, W_{j,-1}^{k},\, W_{j,-1}^{e}\right\} \tag{4}$$

Unemployed workers are assumed to pay taxes, so that nominal disposable income is given by:

$$YD_{jU} = \left(1-\theta_j\right) \cdot UB_j \cdot N_{jU} + i_{d,-1} D_{jU,-1} \tag{5}$$

Wage earners purchase goods from sector *C*, services from sector *S*, and energy from sector *E*. Following Godin (2013), households are assumed to compute a consumer price index (cpi_j) based on their consumption preferences β^i_j and prices:

$$cpi_j = \beta_j^c p_c + \beta_j^s p_s + \beta_j^e p_e \tag{6}$$

They also assess a household group-specific rate of inflation:

$$\pi_j = \frac{cpi_j - cpi_{j,-1}}{cpi_{j,-1}} \tag{7}$$

The consumer price index can be used to calculate disposable income in real terms. The model adopts the Haig-Simons definition of real disposable income, which includes gains or losses of real wealth from one period to the next owing to inflation (Godley and Lavoie 2007: 140, 290):

$$yd_{jz} = \frac{YD_{jz}}{cpi_j} - \frac{\pi_j \cdot D_{jz,-1}}{cpi_j}\ ,\ \forall z \in \left\{E,U\right\} \tag{8}$$

The following equation tracks the change in nominal deposits. This is partly determined by savings, which is simply the difference between current disposable income and consumption. However, following Dafermos and Papatheodorou (2015), we also account for the change in deposits DT_j that occurs as some households move between employment and unemployment. For employed workers, DT_j is added to deposits, whereas for unemployed workers, it is subtracted.

$$D_{jE} = YD_{jE} - C_{jE} + DT_j + D_{jE,-1} \tag{9}$$

$$D_{jU} = YD_{jU} - C_{jU} - DT_j + D_{jU,-1} \tag{10}$$

Deposits are assumed to be equally distributed between the members of a household category, so that the amount moved by a household as its employment status changes is simply the average amount. If the rate of growth of the unemployed is higher than the rate of growth of the labour force, the amount of deposits moved from the stock of the employed to the stock of the unemployed is given by:

$$DT_j = N_{jU,-1}\left(\hat{N}_j - \hat{N}_{jU}\right)\cdot\frac{D_{jE,-1}}{N_{jE,-1}} \;\; if \;\; \hat{N}_{jU} > \hat{N}_j \tag{11}$$

where a ‘hat’ on a variable means its rate of growth. In the opposite case, the equation is:

$$DT_j = N_{jU,-1}\left(\hat{N}_j - \hat{N}_{jU}\right)\cdot\frac{D_{jU,-1}}{N_{jU,-1}} \;\; if \;\; \hat{N}_{jU} < \hat{N}_j \tag{12}$$

The deposits moved, captured by DT, are now those of the new N_{jE} or N_{jU} who are not simply the result of population growth. The real value of deposits is:

$$d_{jz} = \frac{D_{jz}}{cpi_j} \tag{13}$$

Real consumption is determined by:

$$c_{jz} = N_{jz}\frac{\alpha_{1,jz}\cdot yd_{jz}^{ex} + \alpha_{2,jz}\cdot d_{jz,-1}}{N_{jz,-1}} \tag{14}$$

Here, $\alpha_{1,jz}$ and $\alpha_{2,jz}$ are, respectively, the propensity to consume out of income and wealth. We assume that:

$$\alpha_{1,LU} > \alpha_{1,MU} > \alpha_{1,HU} > \alpha_{1,LE} > \alpha_{1,ME} > \alpha_{1,HE} > \alpha_{1,CA}$$

$$\alpha_{2,LU} > \alpha_{2,MU} > \alpha_{2,HU} > \alpha_{2,LE} > \alpha_{2,ME} > \alpha_{2,HE} > \alpha_{2,CA}$$

$$\alpha_{1,jz} > \alpha_{2,jz}$$

However, the current calibration of the model has only allowed these assumptions to be respected for α_1, not for α_2 (see Table A2.1). This shortcoming is largely due to inconsistencies in the allocation of deposits across household groups, which we intend to correct in a later version of the model.

	Unemployed low-skilled	Unemployed medium-skilled	Unemployed high-skilled	Employed low-skilled	Employed medium-skilled	Employed high-skilled	Capitalists
Propensity to consume out of income	0.95	0.9	0.9	0.86	0.81	0.75	0.73
Propensity to consume out of wealth	0.025	0.06	0.035	0.065	0.007	0.098	0.05

Table A2.1. Parameter values for the propensities to consume out of income and wealth in the current model calibration.

Also in equation (14), yd_{jz}^{ex} is the expected real disposable income of the current period. We assume that the current expected income of a certain wage-earner category is equal to its realized income of the last period:

$$yd_{jz}^{ex} = yd_{jz,-1} \tag{15}$$

Households have two sources of funds to finance their consumption; the flow of income over the period and the opening stock of wealth (hence the lag on wealth). The income not consumed will be added to the stock of wealth at the end of the period. The following logic of consumer behaviour is taken from Godley and Lavoie (2007: 66; 78-80): At the beginning of the period, households decide how much to consume throughout the period, based on their expected income. Incorrect expectations do not affect current consumption, showing up instead as unforeseen changes in deposit holdings. Nominal consumption is given by:

$$C_{jz} = c_{jz} \cdot cpi_j \tag{16}$$

Household consumption is allocated across three sectors: the consumption goods and services sector, the social economy, and the energy sector. The following equation determines real consumption, obtained as the preference-determined share of total nominal consumption, deflated by the price of the sectoral good, p_i:

$$c^i_{jz} = \frac{\beta^i_j \cdot C_{jz}}{p_i}, \ \forall i \in \{c,s,e\}, \ \forall j \in \{L,M,N\}, \ \forall z \in \{E,U\} \tag{17}$$

A2.2. Households of capitalists

The dynamic model requires the number of households in each category to be defined, except for capitalist households, which are defined in aggregate terms. Capitalists construct their own consumer price index and inflation rate:

$$cpi_{CA} = \beta^c_{CA} p_c + \beta^s_{CA} p_s + \beta^e_{CA} p_e \tag{18}$$

$$\pi_{CA} = \frac{cpi_{CA} - cpi_{CA,-1}}{cpi_{CA,-1}} \tag{19}$$

Nominal disposable income is the sum of distributed profits net of dividend taxes, plus interest rate payments on deposits:

$$YD_{CA} = (1-\theta_{CA}) \cdot (FD_c + FD_s + FD_k + FD_e + FD_b) + i_{d,-1} D_{CA,-1} \tag{20}$$

Real disposable income is:

$$yd_{CA} = \frac{YD_{CA}}{cpi_{CA}} - \frac{\pi_{CA} \cdot V_{-1}}{cpi_{CA}} \tag{21}$$

The nominal wealth of capitalist households is the sum of deposits and the net worth of firms (which will be defined in a later section). Firms are assumed to be privately owned; there is no stock market.

$$V = D_{CA} + NW^{c} + NW^{s} + NW^{k} + NW^{e} \tag{22}$$

Real wealth is given by:

$$v = \frac{V}{cpi_{CA}} \tag{23}$$

As in the case of wage earners, we assume that capitalists save all their unspent income as bank deposits. However, their consumption decisions depend not only on their deposit holdings, but also on the net wealth of firms. The consumption equations are:

$$c_{CA} = \alpha_{1,CA} \cdot yd_{CA} + \alpha_{2,CA} \cdot v_{-1} \tag{24}$$

$$C_{CA} = c_{CA} \cdot cpi_{CA} \tag{25}$$

$$c^{i}_{CA} = \frac{\beta^{i}_{CA} \cdot C_{CA}}{p_i}, \ \forall i \in \{c, s, e\} \tag{26}$$

Appendix 3: Technical appendix to section 3

A3.1. Output

Economic activity is largely demand-led, so that the output of the consumption and social economy sectors is simply determined by the sum of consumer demand:[33]

$$y_c = c_{LE}^c + c_{LU}^c + c_{ME}^c + c_{MU}^c + c_{HE}^c + c_{HU}^c + c_{CA}^c + c_G^c \tag{27}$$

$$y_s = c_{LE}^s + c_{LU}^s + c_{ME}^s + c_{MU}^s + c_{HE}^s + c_{HU}^s + c_{CA}^s + c_G^s \tag{28}$$

Here, c_G^i is real consumption by the government sector. The output of capital goods equals investment, which in EUROGREEN is only undertaken by private firms:

$$y_k = i_c + i_s + i_k + i_e \tag{29}$$

Energy is both an intermediate and a final good, consumed by all industries except the energy sector itself[34], as well as by households and the government. Real output of energy is given by:

$$y_e = c_c^e + c_s^e + c_k^e + c_{LE}^e + c_{LU}^e + c_{ME}^e + c_{MU}^e + c_{HE}^e + c_{HU}^e + c_{CA}^e + c_G^e \tag{30}$$

In some scenarios, we have included a separate renewable energy sector, so that the regular energy sector described above may be thought of as producing non-renewable energy. The output of renewable energy is driven by supply, i.e., by the size of the capital stock of the sector as well as capital productivity. The renewable energy sector may be considered a state enterprise. Investment in the sector is equal to the revenues obtained from the energy tax levied on the non-renewable sector (see section A3.7,

[33] Because population and the labour force are exogenous variables, output is not purely demand-determined. The labour force does not respond endogenously to an increase in the demand for labour, so the model must be calibrated such that unemployment does not turn negative. In future versions of the model, we intend to include an endogenous dampening effect of full employment overshoot, so that unemployment remains positive in all cases.
[34] The energy sector instead consumes imported oil, which is modelled separately from the national production of energy.

equations 49 and 50, and A5.2, equation 67). The renewable energy sector has not yet been fully incorporated into the model, in that it does not employ workers, does not generate profits or taxes, and does not contribute to GDP. However, investment in the sector does add to the demand for capital goods from sector K, although only to a small extent because of the small size of the renewable energy sector relative to the entire productive sector. The output of renewable energy is consumed by households at no charge, and reduces their consumption of non-renewable energy in direct proportion.[35]

A3.2. Capital

The level of utilization of the capital stock (capacity utilization), u, is defined as:

$$u_i = \frac{y_i}{y_{fc,i}} \text{ , } \forall i \in \{c, s, k, e\} \tag{31}$$

Full-capacity output, y_{fc}, is the product of capital productivity, ξ_i, and the capital stock:

$$y_{fc,i} = \xi_i \cdot k_{i,-1} \text{ , } \forall i \in \{c, s, k, e\} \tag{32}$$

The lags in the above equation reflect the model's assumption that the output of the current period is produced using the stock of capital in existence at the end of the previous period (which is the same as the beginning of the current period). Full capacity is here considered as 'practical capacity', defined as "the output achieved with normal length of working time, with sufficient shut-downs to allow for repairs and maintenance, and without disturbance in the smooth running of the production process" (Steindl 1952 cit. in Lavoie 2014: 148). It is sometimes useful to express current output, based on the above equations, as:

$$y_i = u_i \cdot \xi_i \cdot k_{i,-1}$$

We can use (31) and (32) to express capital productivity as:

[35] However, in our simulations, the consequent savings for households cause a certain rebound effect for non-renewable energy consumption.

$$\xi_i = \frac{y_i}{u_i \cdot k_{i,-1}}$$

In EUROGREEN, capital productivity is typically treated as a constant. This assumption is one of the 'stylized facts' noted by Kaldor (1961).[36]

A3.3. Volume of investment

The volume of investment is determined by a simplified version of the Kaleckian investment function in Lavoie and Godley (2001), omitting some of the financial explanatory variables. At the beginning of the period, firms determine the desired rate of capital accumulation, g_k (excluding capital replacement), on the basis of the previous period's level of capacity utilization, u, and cash-flow ratio, r_{cf}.[37] Firms' sensitivity to these variables is captured by the parameters γ_1 and γ_2. Thus (with sectoral indices omitted throughout this section):

$$g_k = \gamma_1 \cdot \left(u_{-1} - u^T\right) + \gamma_2 \cdot r_{cf,-1} \ , \ \forall i \in \{c, s, k, e\} \tag{33}$$

The cash-flow ratio is defined as retained profits, FU, over the first lag of the nominal stock of capital:

$$r_{cf,-1} = \frac{FU}{p_{k,-1} k_{-1}} \tag{34}$$

The amount of gross investment is given by:

$$i = \max\{g_k + \delta, 0\} \cdot k_{-1} \tag{35}$$

[36] "Stylized facts are empirical regularities that can be seen clearly without using sophisticated econometric techniques (Summers, 1991). Stylized facts are not relations that are true in all countries in all periods of time but are statistical tendencies" (Csereklyei et al. 2014: 2).

[37] In an alternative specification that we might use, the desired rate of capital accumulation is positive when u and r_{cf} are above their normal values; u_n and $r_{cf,n}$.

A maximum condition is included to rule out negative values that are not economically meaningful (negative flows of investment spending). The real stock of capital is:

$$k = i + (1-\delta)k_{-1} \tag{36}$$

Firms finance their investment firstly out of retained earnings. Whenever their planned investment exceeds retained earnings, firms borrow the difference from private banks. If investment is smaller than retained earnings in any given period, firms will use the surplus to reduce their stock of bank loans. Consequently, the stock of loans is:

$$L_i = p_k i_i - FU_i + L_{i,-1} \,, \ \forall i \in \{c, s, k, e\} \tag{37}$$

The net worth of firms is determined as the residual difference between firms' assets and liabilities. As the balance sheet matrix (Table A1.1 in Appendix 1) shows, this means that net worth is given by:

$$NW_i = p_k k_i - L_i$$

However, in system dynamics modelling, it is convenient to define net worth as a stock with inflows and outflows rather than the difference between two stocks. We therefore combine the equations for the stocks of capital (36) and loans (37) to define the change in net worth as the inflow of retained earnings minus the outflow of depreciation costs:

$$NW_i = FU_i - \delta \cdot p_k \cdot k_{i,-1} + NW_{i,-1} \,, \ \forall i \in \{c, s, k, e\} \tag{38}$$

A3.4. Type of investment

At the beginning of each period, firms decide whether to invest in labour-saving or energy-saving technology. This may be called, respectively, 'grey' and 'green' investment. The decision is based on the evolution of χ; the ratio between the energy price and the average effective wage (sectoral indices omitted):

$$\chi = \frac{p_e}{\frac{W_L N_{LE} + W_M N_{ME} + W_H N_{HE}}{N_E}} \tag{39}$$

If there has been an increase in χ in the previous period ($\chi_{-1} > \chi_{-2}$), firms will decide to undertake green investment, improving the energy efficiency of the capital stock. Conversely, if the ratio has decreased or remained constant, firms choose grey investment, accelerating the growth of labour productivity (which, as we will see, will also cause wages to rise, although to a lesser degree). The evolution of the energy efficiency of production is thus embodied in the existing capital stock.[38] We define the average energy conversion efficiency as:

$$\bar{\eta} = \frac{\eta \cdot i - \bar{\eta}_{-2} \cdot \delta \cdot k_{-1} + \bar{\eta}_{-1} \cdot k_{-1}}{k} \tag{40}$$

Here, a bar denotes an average, η without bar is the energy efficiency of the capital installed in the current period, k is the capital stock, i is investment, and δ is the rate of depreciation. Note that depreciated capital has a somewhat larger lag (lower efficiency), and that the current efficiency is incorporated into both replacement investment and new investment. The rate of growth of energy efficiency, g_η, is assumed to decrease asymptotically as the energy efficiency draws closer to its maximum value:

$$g_\eta = g_{\eta,p}\left(\frac{\eta_{\max} - \eta_{-1}}{\eta_{\max} - \eta_0}\right) \tag{41}$$

This growth rate represents the highest practically achievable efficiency improvement. Under green investment, this potential is (almost) fully realized. In contrast, with grey investment, efficiency improvements are smaller, but still positive. The difference is captured by the parameter ι:

[38] This embodied technical change approach to energy efficiency does not capture the potential for more immediate reductions in energy consumption at the level of the firm through disembodied technical change (e.g., learning by doing), short-term substitution between inputs, or adjusting heating and air conditioning systems or reducing miles travelled in company cars and corporate jets.

$$\eta = \left[1 + \iota \cdot g_{\eta}\left(\frac{\eta_{max} - \eta_{-1}}{\eta_{max} - \eta_{0}}\right)\right]\eta_{-1} \tag{42}$$

$$\iota = \begin{cases} \iota_{HIGH} \ \ if \ \chi_{-1} > \chi_{-2} \\ \iota_{LOW} \ \ if \ \chi_{-1} \leq \chi_{-2} \end{cases} \tag{43}$$

The different impact of green vs. grey investment on labour productivity is represented by the different values taken by the parameter σ_1, which multiplies the rate of capital accumulation, g_k (net of depreciation).[39]

$$\sigma_1 = \begin{cases} \sigma_{1,LOW} \ \ if \ \chi_{-1} > \chi_{-2} \\ \sigma_{1,HIGH} \ \ if \ \chi_{-1} \leq \chi_{-2} \end{cases} \tag{44}$$

The modelling of labour productivity is described further in Appendix 4.

A3.5 Industrial energy consumption

All industrial sectors consume energy, except the energy sector itself (see footnote 34). Energy consumption, expressed in real terms (i.e., units of energy), is:

$$c_i^e = \frac{y_i}{\overline{\eta}_{i,-1} \cdot \varepsilon_i}, \ \forall i \in \{c, s, k\} \tag{45}$$

where y is real output, η bar is the average energy efficiency of fixed capital, and ε is the energy service efficiency of the product. This combination of two distinct energy efficiencies – each referring to different stages of the energy flow – is preliminary, and will probably not be used in future versions of the model because of the difficulties of

[39] Unlike the rate of growth of gross investment, i/k_{-1}, the rate of net investment, g_k, can be negative. Thus, the rate of growth of labour productivity can also be negative.

empirical estimation. In the current version, the starting values of energy efficiencies are notional rather than empirically based.[40]

A3.6. Costing

EUROGREEN adopts a simplified post-Keynesian view of the cost curves facing firms (Fig. A3.1). The figure shows constant marginal costs (MC) up to practical capacity (FC), after which they rise exponentially up to theoretical full capacity (FC_{th}). At FC, "[t]here is a discontinuity in the marginal cost curve because (…) it is assumed that the over-extensive use of machines will drastically swell replacement costs and because workers will most likely have to be paid overtime" (Lavoie 2014: 150).[41]

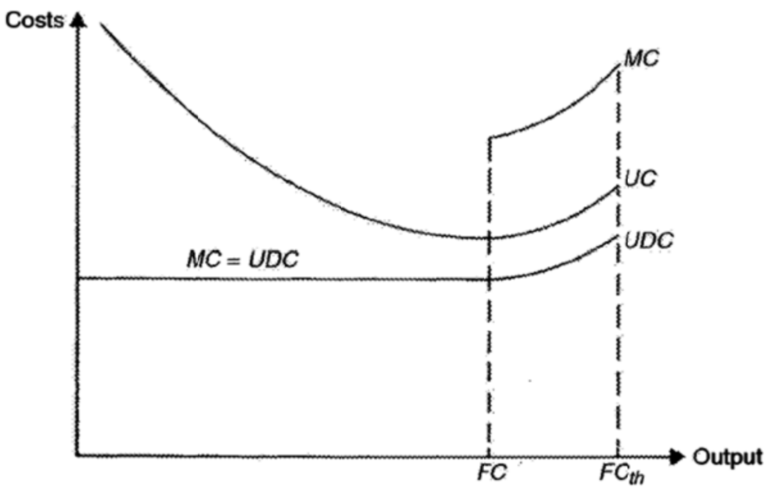

Figure A3.1. Marginal costs (MC), unit direct costs (UDC) and unit costs (UC) of the post-Keynesian firm. Reproduced from Lavoie (2014: 150).

[40] With regard to energy variables, the EUROGREEN model has not yet incorporated any empirical data. Households' energy consumption, as a share of their total consumption expenditures, has been roughly approximated to the data, but firms' energy variables have been freely assumed. In particular, the starting values for the energy consumption and energy efficiency of the industrial sectors are not empirically based. For example, as mentioned above (section 3, footnote 22), the starting value for the productive sector's share of the economy's final energy consumption is underestimated at just 6%. Furthermore, the potential trajectories of energy efficiency have not been compared to existing assessments in the literature. The correction of these shortcomings is a priority of future work on the model.

[41] This approach differs from mainstream microeconomics, where marginal cost curves are U-shaped and rising before full capacity. Among the empirical support for the post-Keynesian view is a survey conducted by a team of mainstream (New Keynesian) economists (Blinder et al. 1998), in which "only 11 per cent [of respondents] answered that marginal costs were rising; 40 per cent said they were declining, and 49 per cent said they were constant" (Lavoie 2014: 151; see also Downward and Lee 2001).

In EUROGREEN, the unit costs (also known as average costs) foreseen by the entrepreneur are a decreasing function of output up to practical full capacity. When utilization is above practical full capacity, unit costs are assumed to rise exponentially, as captured by the last term:

$$UC_i = \frac{W_L^i N_{LE}^i + W_M^i N_{ME}^i + W_H^i N_{HE}^i + p_e c_i^e + \delta p_k k_{i,-1}}{y_i} + \psi \left(u_i - 1\right)^2, \ \forall i \in \{c, s, k\} \quad (46)$$

$$where\ \psi = 0\ if\ u_i \leq 1$$

The corresponding equation for the energy sector is:

$$UC_e = \frac{W_L^e N_{LE}^e + W_M^e N_{ME}^e + W_H^e N_{HE}^e + p_o q_o + \delta p_k k_{e,-1}}{y_e} + \psi \left(u_e - 1\right)^2 \quad (47)$$

A3.7. Pricing

EUROGREEN uses cost-plus pricing, with prices administered by firms rather than determined by the interaction of supply and demand. This is consistent with post-Keynesian price theory (Lee 1999). However, cost-plus pricing does not apply to primary sectors, where prices are strongly influenced by demand. Nevertheless, we assume that the energy sector takes the price of oil as given by the world market, and that it sets the output price of energy (refined fuels and electricity) in relation to this. In other words, all four industries set prices by multiplying lagged unit costs by a mark-up factor, φ:

$$p_i = \left(1 + \phi_i\right) UC_{i,-1} \quad (48)$$

Mark-ups are treated as fixed parameters.[42] In calibrating the model, we have started from empirically estimated mark-ups for the French economy taken from Christopoulou and Vermeulen (2012; 2008), whose calculations are based on EU KLEMS data.

[42] In future work, we plan to include scenarios generated by manipulating the mark-up of the social economy, approximating this sector to a non-profit or 'sufficiency' economy.

However, these values have been modified significantly in the process of calibration (see Table A3.1).

	Sector C	Sector S	Sector K	Sector E
Empirical estimation	0.21	0.20	0.15	0.38
Calibration	0.24	0.13	0.15	0.25

Table A3.1. Comparison of empirically estimated and calibrated mark-ups. Empirical values are mapped onto the model's four sectors as follows: Sector C is based on the weighted average mark-up of all sectors (manufacturing, construction, and services) for 1981-2004, reported in Christopoulou and Vermeulen (2012: 61, Table 1). Sector C is a rough estimate based on NACE (2 digit Rev 1.1) sectors 75, 80, 85, and 91-93 for the same period in Christopoulou and Vermeulen (2008: 27, Table A1.a). Sector K corresponds to the weighted average mark-up in manufacturing for 1993-2004 (Christopoulou and Vermeulen 2012: 61, Table 2). Sector E is a weighted average that we have calculated from the data for NACE sectors 40 and 41 (corresponding to NACE Rev. 2 sectors D+E) for 1981-2004, reported in Christopoulou and Vermeulen (2012: 70-71, Appendix A1.a). For sector E, we have used the same aggregation procedure as in the empirical study, i.e., weighing the original sectoral estimates by gross output in the year 2000.

The price of energy also includes an energy tax factor, θ_e:

$$p_e = (1+\theta_e)(1+\phi_e)UC_{e,-1} \tag{49}$$

θ_e is calculated from the Regulating Energy Tax (RET) rate, τ_e, set by the government:

$$\theta_e = \frac{\tau_e}{1-\tau_e} \tag{50}$$

The energy tax may be compared with – but does not aspire to represent – the existing French *Domestic Consumption Tax on Energy Products* (TICPE), which is an excise tax levied on motor fuel and heating fuel as a fixed amount per unit of volume.

Total entrepreneurial profits are given by:

$$F_i = p_i y_i - W_L^i N_{LE}^i - W_M^i N_{ME}^i - W_H^i N_{HE}^i - p_e c_{i,e} - i_{l,-1} L_{i,-1} \ , \ \forall i \in \{c, s, k\} \qquad (51)$$

$$F_e = (1 - \tau_e) p_e y_e - W_L^e N_{LE}^e - W_M^e N_{ME}^e - W_H^e N_{HE}^e - p_o q_o - i_{l,-1} L_{e,-1} \qquad (52)$$

In each modelling period, firms are assumed to distribute a fixed proportion, μ_i, of their profits from the previous period, so that dividends FD_i and retained earnings FU_i are:

$$FD_i = \mu_i F_{i,-1} \ , \ \forall i \in \{c, s, k, e\} \qquad (53)$$

$$FU_i = (1 - \mu_i) F_{i,-1} \ , \ \forall i \in \{c, s, k, e\} \qquad (54)$$

Appendix 4: Technical appendix to section 4

A4.1. Employment

Employment (i.e., the number of employed workers by skill level) in each industry is given by (sectoral indices omitted throughout this section):

$$N_{HE} = \frac{\sigma_H \cdot y_{fc}}{\lambda \cdot h} \tag{55}$$

$$N_{jE} = \frac{\sigma_j \cdot y}{\lambda \cdot h}, \ \forall j \in \{L, M\} \tag{56}$$

where the σ:s are parameters determining the skill composition of employment, y_{fc} and y are, respectively, full-capacity and actual output, λ is hourly labour productivity, and h is average annual hours worked per employee. The skill composition parameters are fixed at a value calculated from the empirical data, $\sigma = \sigma_0$. For fixed labour, the calculation of σ_H involves capacity utilization data from the manufacturing sector (so that the σ:s only sum to 1 when utilization is at full capacity, $u = 1$):

$$\sigma_{H,0} = \frac{u_0 \lambda_0 h_0 N_{H,0}}{y_0} = \frac{u_0 y_0 N_{H,0}}{N_E y_0} = \frac{u_0 N_{H,0}}{N_E}$$

A4.2. Labour productivity

Labour productivity (which is expressed in hourly rather than annual terms in the model) evolves according to the following equation, which is assumed to be equal for all skill-categories:

$$\lambda = \left(1 + \sigma_0 + \sigma_1 g_k + \sigma_2 g_{w_{AVG}} - \sigma_3 g_h\right) \lambda_{-1} \tag{57}$$

where σ_0 is an exogenous positive term, σ_1 is determined by the type of investment (see Appendix 3, equation 44), g_k is the rate of capital accumulation, g_{wAVG} is the average real wage of the corresponding industrial sector, g_h is the change in working hours, and σ_2 and σ_3 are positive parameters. Let's illustrate the direct impact of WTR on labour productivity with an example: If hours are reduced by 25% from 8 to 6 hours and σ_3 = 0.2, the resulting increase in labour productivity is -0.2*(-0.25) = 0.05, i.e., 5%. Although simulations start in 2014, the initial values for labour productivity use data for 2008, due to the lack of more recent data in the EU KLEMS database. Initial labour productivity is calculated using data on gross value added (in 2010 prices) from INSEE together with data on the number of persons engaged and total hours worked by persons engaged from EU KLEMS.

A4.3. Wages

In the baseline scenario, annual nominal wages for all skill levels are assumed to depend positively on the rate of growth of hourly labour productivity, g_λ, and negatively on the rate of growth of the number of unemployed workers:[43]

$$W_j = \left(1 + \omega_1 \, g_\lambda - \omega_2 \, \hat{N}_{jU}\right) W_{j,-1}, \ \ \forall j \in \{L, M, H\} \tag{58}$$

Annual real wages are:

$$w_j = \frac{W_j}{cpi_j}, \ \forall j \in \{L, M, H\} \tag{59}$$

[43] In future versions of the model, we intend to modify the impact of unemployment on wages so as to consider population dynamics. That is, we will define wages as a function of the rate of growth of the rate of unemployment, not the rate of growth of the absolute number of unemployed workers.

Appendix 5: Technical appendix to section 5

A5.1. Bank sector

We make the simplifying assumption that all interest rates are exogenous, such that the rate on bank loans, i_l, is higher than the rate on government bonds, i_b, which in turn is higher than the rate on deposits, i_d. We use the following rates: i_l = 1.5%, i_b = 1%, i_d = 0.5%. Bank profits are given by:

$$F_b = i_{l,-1} \sum L_{-1} + i_{b,-1} B_{-1} - i_{d,-1} \sum D_{-1} \tag{60}$$

The profits are distributed in full, with a one-period lag:

$$FD_b = F_{b,-1} \tag{61}$$

A5.2. Government

Real public consumption expenditures are:

$$c_G^i = a_G \left(\sum c_{jz}^i + c_{CA}^i \right), \ \forall i \in \{c, s, e\}, \ \forall j \in \{L, M, N\}, \ \forall z \in \{E, U\} \tag{62}$$

with:

$$a_G = \frac{\alpha_G}{1 - \alpha_G} \tag{63}$$

In the current calibration, we use a notional value for the government's share of total real consumption expenditures, αG = 21.5%, so that aG ≈ 0.274.[44] Total nominal public consumption expenditures are given by:

$$C_G = p_c c_G^c + p_s c_G^s + p_e c_G^e \tag{64}$$

[44] Note that α_G is not equal to public spending as a share of GDP, since investment is not included.

Nominal unemployment benefit transfers are determined as:

$$UB = UB_L \cdot N_{LU} + UB_M \cdot N_{MU} + UB_H \cdot N_{HU} \tag{65}$$

with UB_j defined by equation (4). The government funds its deficit by selling a single type of bonds, B. We assume that all government debt is held by private banks, thus avoiding the modelling of households' portfolio choice. Total nominal government expenditure is:

$$G = C_G + UB + i_{b,-1} \cdot B_{-1} \tag{66}$$

Total nominal government revenue is given by:

$$\begin{aligned} T = {} & \theta_L \left(\sum W_L^i N_{LE}^i + UB_L N_{LU} \right) + \theta_M \left(\sum W_M^i N_{ME}^i + UB_M N_{MU} \right) \\ & + \theta_H \left(\sum W_H^i N_{HE}^i + UB_H N_{HU} \right) + \theta_{CA} \sum FD_i + \tau_e p_e y_e \end{aligned} \tag{67}$$

The stock of government debt is:

$$B = G - T + B_{-1} \tag{68}$$

Appendix 6: Additional equations

All properly defined SFC models have a hidden or redundant equation that should always be satisfied due to the 'watertight' accounting framework underlying the model. The hidden equation cannot be fed into the computer without creating a new variable, since this would make the model overdetermined. The hidden equation of EUROGREEN states that the stock of monetary assets are equal to the stock of monetary liabilities, as can be read from the balance sheet matrix. Thus, the following variable SFC_1 should always be equal to zero:

$$SFC_1 = \sum D - \left(\sum L + B\right)$$

Nominal GDP is defined as the sum of household consumption, investment, and government consumption:

$$GDP = p_c y_c + p_s y_s + p_k y_k + p_e \left[y_e - \left(c_c^e + c_s^e + c_k^e \right) \right]$$

Real GDP is obtained by constructing a GDP deflator:

$$gdp = Deflator \cdot GDP$$

$$Deflator = z_c\, p_c + z_s\, p_s + z_k\, p_k + z_e\, p_e$$

$$z_i = \frac{p_i\, y_i}{GDP},\ \ \forall i \in \{c, s, k\}$$

$$z_e = \frac{p_e \left(\sum c_{jz}^e + c_{CA}^e \right)}{GDP},\ \ \forall j \in \{L, M, N\},\ \ \forall z \in \{E, U\}$$

The public debt to GDP ratio is:

$$\frac{B}{GDP}$$

The fiscal deficit as a percentage of GDP is:

$$\frac{G-T}{GDP}$$

The sectoral rate of profit is:

$$\frac{F_i}{p_{k,-1}k_{i,-1}}, \ \forall i \in \{c, s, k, e\}$$

The profit share of income is:

$$\frac{F_c + F_s + F_k + F_e + F_b}{GDP}$$

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