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Analysis

Energy Metabolism of 28 World Countries: A Multi-scale Integrated Analysis

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ABSTRACT

In this paper the Multi-Scale Integrated Analysis of Social Metabolism (MuSIASEM) is used to investigate the metabolic profile of 28 world countries. The years considered are 1995 and 2007 and the socio-economic and environmental data included in the World Input-Output Database (WIOD) are used to provide consistent comparisons between countries. The analyses are performed by considering the entire society (Level N), the household and the paid sectors (Level N-1) and the different economic sectors (Level N-2). The main results show that, despite the differences existing between countries, the increasing energy throughput and per-capita consumption contributed to change the metabolic profile of the countries considered in this paper.

1. Introduction

Human societies have always been dependent on material and energy use. In recent time, however, the increasing level of per-capita consumption and the pressure generated by a rising world population have increased the worldwide energy and material demand. Based on data provided by Arto et al. (2012)and by the International Energy Agency (IEA, 2015), the quantity of material extracted increased by around 43% (between 1995 and 2007) and the world energy consumption by almost 100%, rising from 4666 Mtoe in 1973 to 9302 Mtoe in 2013. Fossil fuels have been the main source of energy supply, accounting today for around 82% of the total energy use (World Bank, 2016). The consequent impact on resource availability, pollution and unequal distribution of wealth are some of the main elements raising concerns related to possible instabilities and crisis. Over the last few decades, different models have been proposed to investigate the mutual relationships existing between the humans and the natural environment and the concept of social metabolism has been proposed to investigate the process of energy and material transformation taking place on societies (Martinez-Alier, 1987; Fischer-Kowalski, 1998). Based on the idea that the human environment is strictly dependent on the natural environment, the social metabolism analyses the energy and the material use as fundamental elements for the maintenance and development of societies. The main objective is to investigate how variation in energy, material and human time allocation can generate impact on both social and environmental elements. The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) is an accounting framework specifically design to investigate the size, the allocation and the human and natural dependencies of societies (Giampietro and Mayumi, 1977, 2000). By using the MuSIASEM approach, this paper compares the metabolic profile of 28 world countries in 1995 and 2007. The main objective is to provide an overview of the variations that have taken place and to investigate the main elements responsible for changes. The paper is structured as follow: Section 2 introduces the methodology. Section 3 presents the study area and the data sources. In Section 4 the main results are reported and interpreted. Section 5 includes discussion, future development and limitations. Section 6 concludes.

2. Social Metabolism and MuSIASEM Methodology

The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) has been proposed by Giampietro and Mayumi (1977, 2000) based on the integration of various concepts related to complex system theory (Prigogine, 1961, 1978; Maturana and Valera, 1980; Odum, 1971, 1983, 1996; Ulanowicz, 1986, 1995; Rosen, 1958, 2000; Zipf, 1941; Morowitz, 1979; Kauffman, 1993; Ahl and Allen, 1996; Koestler, 1969) post-normal science (Funtowicz and Ravetz, 1994) and bioeconomics (Georgescu-Roegen, 1971, 1977) (for exhaustive descriptions please see Mayumi, 1999, Ramos-Martin et al., 2007 and Giampietro et al., 2009). The main idea is to consider societies as metabolic structures that use flows and funds to sustain and expand. According to the definition reported by Velasco-Fernandez et al. (2015),

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flows are elements that enter into the system, as energy or material and that are transformed by the socio-economic processes. Funds are elements that are sustained by the flows and that preserve their identity, as for example capital or human time. The way in which flows and funds are combined characterise the metabolic profile of societies. The analysis of the relationships existing between energy, materials and socio-economic variables, as human time, demography and economic elements, provides information about the way in which societies evolve and self-organise. During the last decade, the MuSIASEM approach has proven to be particularly useful to analyse how technological development and acceleration of energy and material use, generates changes in the metabolic structure of societies. The increasing use of exosomatic energy, defined as the non-human body energy source, has been related to changes in demographic structure, economic activities, human time allocation, social stability and environmental impacts (Mayumi, 1991; Falconi-Benitez, 2001; Ramos-Martin, 2001; Ramos-Martin and Giampietro, 2005; Eisenmenger et al., 2007; Ramos-Martin et al., 2009; Serrano-Tovar and Giampietro, 2014; Velasco-Fernandez et al., 2015; Ginard-Bosch and Ramos-Martin, 2016). According to this approach, the accounting framework proposed by MuSIASEM is specifically designed to study biophysical and socioeconomic elements in an integrated way (Giampietro and Bukkens, 2015). The analysis of the interrelationships existing between them is useful to identify constraints that can affect the evolution of the system as well as impacts that can be generated both on the human and on the natural environment. Since the MuSIASEM approach recognises the idea that societies are complex systems operating at different levels, the proposed accounting framework includes different scales of analysis. The objective is to investigate societies as a whole or disaggregated between activities. The main levels of analysis can be summarised as:

- Level N consider the entire society;
- Level N-1 disaggregates society between consumption and production activities, respectively defined as household and paid sectors. The paid sector includes all the activities that are responsible for value added generation. The household sector includes the activities related to value added consumption.
- Level N-2 split the paid activities into different subsectors. The economic sectors considered in this paper are reported Table 1.

For every one of the three levels, the energy and the human time constraints are investigated. The mutual relationships existing between them are also taken into account by considering that changes in one level generates impacts in the other levels.

Different variables and indicators have been proposed by the MuSIASEM approach. An overview is reported in Tables 2 and 3. These variables and indicators have been specifically designed to have a multi-level and multi-dimensional structure. The main objective is to analyse both the characteristics of the different compartments of society as well as to take into account the mutual relationships existing between them. This multi-level descriptions, together with the inclusion of quantitative information related to biophysical and socio-economic elements provide an useful tool to investigate the complex relationships and constraints existing between the human and the natural environment.

The MuSIASEM approach has proven to be an effective tool to analyse the characteristics of societies based on population, socio-economic variables and environmental constraints (Velasco-Fernandez et al., 2015; Giampietro and Bukkens, 2015). By using the accounting framework described above, the present paper analyses the energy metabolism of 28 world countries in 1995 and 2007. The results provide an overview of the development path of countries and can be used to support policy in the design of sustainable strategies.

3. Study Area and Data

The study area considered in this paper includes the 28 world countries reported in Table 4. Fourteen of the countries have been classified as western European countries, six countries as eastern European countries and the remaining eighth as extra European areas. This selection of countries has been mainly driven by consistency in data availability. Since the main objective was to provide an overview of the exosomatic energy metabolism of different countries, only the areas with consistent information across all the variables have been considered in this paper. For this reason, all the countries requiring alternative data sources have been excluded.

Based on this data consistency approach, the World Input-Output Database (WIOD) has been used as the main data source for calculation. This database includes a set of socio-economic and environmental information for 40 world countries plus the Rest of the World (for a description of the database see Dietzenbacher et al., 2013). The socio-economic

Table 1
Economic sectors.

Sector	Code	Description
Agriculture	A + B + C	Agriculture, hunting, forestry, mining and quarrying
Industry	D	Manufacturing
	E	Electricity, gas and water supply
	F	Construction
Services	G	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
	H	Hotel and restaurant
	I	Transport, storage and communications
	J	Financial intermediation
	L	Public administration and defence; compulsory social security
	M	Education
	N	Health and social work
	O + P + Q	Other community, social and personal service activities, private households with employed persons

Table 2
MuSIASEM variables.

Level N	Level N-1	Level N-2
Variable/description/unit	Variable/description	Variable/description
THA: Total human time available for one country for one year. It is calculated as: population ∗ 24 h ∗ 365 days It is measured in hours (h)	THA can be disaggregated in: – HA_{PW}: accounts for the hours allocated to the paid sector – HA_{HH}: accounts for the hours allocated to the household sector	HA_{PW} can be disaggregated between the different economic sectors - HA_{PWi}
TET: Total energy throughput quantify the total exosomatic energy consumed by one country in one year. It is measured in megajoule (MJ)	TET can be disaggregated in: – ET_{PW}: accounts for the exosomatic energy consumption of the paid sector – ET_{HH}: accounts for the exosomatic energy consumption of the household sector	ET_{PW} can be disaggregated between the different economic sectors - ET_{PWi}
GDP: Gross domestic product is the value added generated by one country in one year. It is measured in dollar ($)		GDP can be disaggregated between the different economic sectors - GDP_i

Table 3
MuSIASEM indicators.

Level N	Level N-1	Level N-2
Indicator/description/unit	Indicator/description	Indicator/description
EEI: Economic energy intensity. It is calculated as TET/GDP. It is measured in megajoule/dollar (MJ/$)		EEI can be disaggregated between the different economic sectors - EEI_i
	ELPpw: Economic labour productivity. It is calculated as GDP/HA_{PW}. It is measured in dollar/h ($/h)	ELP can be disaggregated between the different economic sectors - ELP_i
EMR_{SA}: Exosomatic metabolic rate. It quantifies the quantity of exosomatic energy consumed per hour of human activity. It is calculated as TET/THA. It is measured in megajoule/h (MJ/h)	EMR_{SA} can be disaggregated in: – EMR_{PW}: accounts for the exosomatic energy consumed per hour in the paid sector. It is calculated as ET_{PW}/HA_{PW} – EMR_{HH}: accounts for the exosomatic energy consumed per hour in the household sector. It is calculated as ET_{HH}/HA_{HH}	EMR_{PW} can be disaggregated between the different economic sectors - EMR_{PWi} It is calculated as ET_{PWi}/HA_{PWi}
GDP_{hour} is the value added generated per hour of human activity. It is calculated as GDP/THA. It is measured in dollar/h ($/h)		GDP_{hour} can be disaggregated between the different economic sectors - $GDP_{hour\,i}$

accounts included in WIOD provide consistent information on the number of hours worked by persons engaged (employees, self-employed and family-workers), exosomatic energy and labour productivity for all the 28 countries considered in this paper. The socio-economic information provided by WIOD are also disaggregated according to the economic sectors reported in Table 1. OECD data have been used for population and GDP (US$ constant prices, constant PPP reference year 2005). The World Input Output Database is suitable to be used to investigate a large set of topics related to economy, society and environment. In the past, it has for example been used to analyse the relationships between economic activities and environmental impacts (Arto et al., 2012, 2014, 2016), to investigate the main drivers on energy use (Andreoni and Galmarini, 2016) and to analyse topics related to global value chain, globalisation and competitiveness (Timmer et al., 2013; Timmer et al., 2014; Costinot and Rodriguez-Clare, 2014; Los et al., 2015). As far as I know, the present paper is the first attempt to use the WIOD database to analyse the metabolic profile of societies.

Table 4
Countries.

Acronyms	Country	Acronyms	Country	Acronyms	Country
WEC	Western European	EEC	Eastern European countries	ExEC	Extra European countries
AUT	Austria	CZE	Czech Republic	AUS	Australia
BEL	Belgium	EST	Estonia	CAN	Canada
DEU	Germany	HUN	Hungary	JPN	Japan
DNK	Denmark	POL	Poland	KOR	Korea
ESP	Spain	SVK	Slovakia	MEX	Mexico
FIN	Finland	SVN	Slovenia	RUS	Russia
FRA	France			TUR	Turkey
GBR	Great Britain			USA	United States
GRC	Greece				
IRL	Ireland				
ITA	Italy				
NDL	Netherlands				
PRT	Portugal				
SWE	Sweden				

4. Results

4.1. Level N – Country Level

The results presented in this section summarise the main variables and indicators reported in Level N of Tables 1 and 2. Based on country level information, they provide an overview of the metabolic performance of the 28 countries considered in this paper. Disaggregated data for countries, variables and indicators are reported in Tables A.1–A.9 of the appendix.

According to data reported in Fig. 1 and in Table A.1 of the appendix, the total energy throughput (TET) increased for all the countries considered in this paper, ad exception of Great Britain and Sweden (−3.0% and −1.1%, respectively). In Great Britain, the reduction of the total energy consumption that has taken place in the paid sector (ET_{PW}) (−680,959 TJ) has driven the reduction of the total energy throughput, while the energy consumed in the household sector (ET_{HH}) increased (+236,597 TJ) (Tables A.3 and A.4 of the appendix). According to data reported in Table A.6 of the appendix, the energy throughput reduced in the manufacturing (−15.1%), in the construction (−15.1%), in the wholesale (−14.1%), in the public administration (−43.2%) and in the education (−16.2%) sectors. However, the largest absolute variations have taken place in the manufacturing (−1.004,989 TJ) and in the public administration sectors (−74,272 TJ). The reduction of activity of the heavy industry sub-sectors (iron and steel, non-ferrous metal, mineral products and chemicals) and the improvements on the heating system and insulation, that have taken place in public administration sectors, have been the main elements influencing the reduction of the total energy throughput (TET) (Department of Business, Energy and Industrial Strategy, 2016). In a similar way, the large investments devoted to reduce the energy consumption of buildings and the Swedish Energy Agency programme oriented to increase consumer's responsibility have been the main factors responsible for the reduction of the total energy throughput (TET) of Sweden (IEA, 2013; Vassileva, 2012). In this country, the household sector has been the main driver of the reduction in the energy throughput (ET_{HH} reduced by 9% between 1995 and 2007), while the energy used in the paid sector (ET_{PW}) remained almost unchanged (+0.1%) (Tables A.3 and A.4 of the appendix).

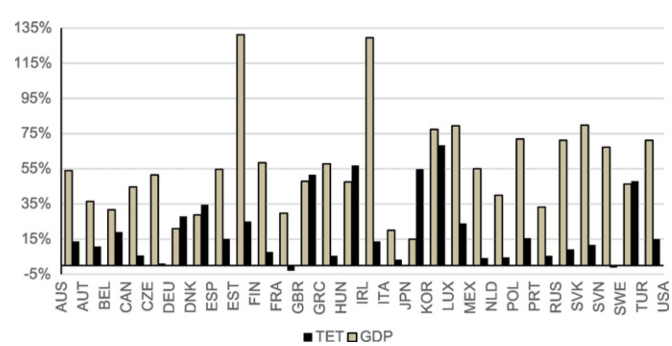

Fig. 1. TET and GDP: percentage variation between the years 1995 and 2007.

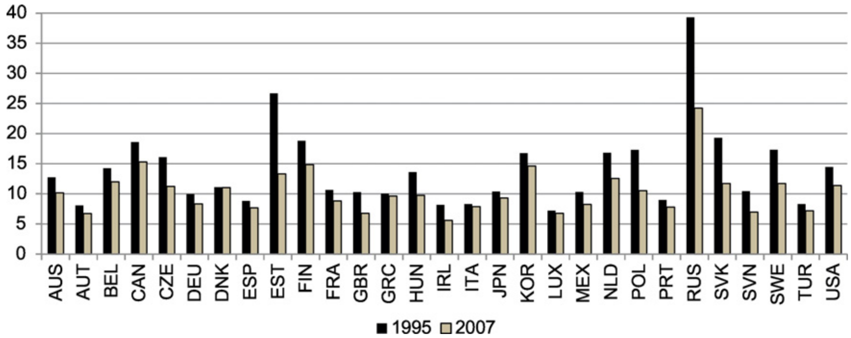

Fig. 2. Energy intensity (EEI = TET/GDP), (MJ/$).

Between the years 1995 and 2007, the gross domestic product (GDP) increased for all the countries considered in this paper. The largest percentage variations have taken place in Ireland (+129.5%), Korea (+77.3%), Russia (+71.1%), Turkey (+71.1%) and in the eastern European countries that during the period considered joined the EU (Estonia +131.2%, Slovakia 79.8%, Poland +71.9%, Slovenia 67.3%). The percentage increase of GDP has been higher than the percentage variation of TET. This trend is also summarised by the quantity of energy used per unit of GDP (TET/GDP), that reduced for all the countries included in this paper. According to data reported in Fig. 2 and in Table A.2 of the appendix, Russia (−38.3%), Great Britain (−34.4%), Sweden (−32.4%) and the eastern European countries, that joined the EU during the period considered, performed the largest energy efficiency increases (Estonia −50.2%, Slovakia, −39.3%, Poland −39.2%, Slovenia −33.2%, Czech Republic −30.2% and Hungary −28.5%). The technological transfer and the EU regulations, together with the externalisation of some of the most energy intensive activities and the increasing contribution of the financial sector have been some of the main factors contributing to reduce the quantity of energy use per unit of GDP (Andreoni and Galmarini, 2016; Fiorito, 2013). Denmark has been the only country with an energy intensity reduction lower than 1% (−0.7%). As reported by Andreoni and Galmarini (2012) the fuel switching that has taken place in the maritime transport sector, has been the main factor influencing the low energy efficiency improvement.

According to data reported in Fig. 3 and in Table A.1 of the appendix, the percentage variation of the total human time (THA), that can be considered as a proxy of the population size, has been generally lower than the percentage variation of the total energy throughput (TET). These data provide evidence that the total energy consumption increase has not been driven by a population growth but it has been generated by an overall per capita energy consumption increase. The only exceptions are Netherlands, where the total human time increased more than the energy throughput (+6% and +4.3%, respectively), Great Britain and Sweden, that as reported above, reduced the total energy consumption during the period considered in this paper. To better investigate this evidence, the following section analyses the variation in the energy consumption for the household and for the paid sectors.

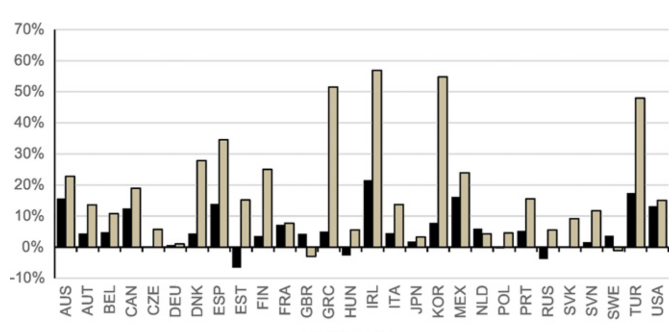

Fig. 3. TET and THA: percentage variation between the years 1995 and 2007.

4.2. Level N-1 – Household and Paid Sector Level

The analysis of the metabolic performance at national level can be complemented by analysis at a lower scale. The Level N-1 disaggregates the human activities between household (HH) and paid sectors (PW). When analysing the performance of the household sector, particular attention needs to be devoted to the demographic structure of society. According to data reported in Table A.1 of the appendix, most of the countries considered in this paper, ad exception of Russia and some of the eastern European countries that joined the EU during the time period considered in this paper (Czech Republic, Estonia, Hungary and Poland) had a population increase (THA). However, since the percentage variation of the time spent in the paid sectors (HA_{PW}) has, in most of the cases, been higher than the percentage variation of the population (THA), the fraction HA_{PW}/THA has increased (Table A.4 of the appendix). This means that the dependency ratio of the non-working and unemployed population decreased. The only countries that increased the dependency ratio have been Czech Republic, Germany, Japan, Korea, Poland, Slovakia and Turkey. On these countries, the percentage variation of HA_{PW} has been lower than the population increase. Aging population and outflow migration of working age citizens have been the main factors affecting this trend. Japan and Germany ranked as two of the top three world aging population countries and Czech Republic and Slovakia experienced large population outflow particular towards western European countries (OECD website).

In terms of energy throughput, twenty-one countries increased the quantity of energy used in the household sector (ET_{HH}) and nineteen of them increased the energy used per unit of time (EMR_{HH}) (Fig. 4 and Table A.4 of the appendix). According to Cleveland et al. (1984), Hall et al. (1986), Pastore et al. (2000), Giampietro et al. (2011) and Velasco-Fernandez et al. (2015) a higher energy throughput per hour of human activity in the household sector can be considered as a proxy of the material standard of living. Larger energy throughput can be associated with more energy services and home appliances that usually increase the overall comfort of non-working time. For the countries that performed a negative variation of EMR_{HH} (Austria, Belgium, Germany, Finland, Netherlands, Poland, Russia, Slovenia and Sweden), the percentage change of the time spent in the household sector has been higher than the percentage variation of the energy throughput and for seven of the countries (Belgium, Germany, Netherlands, Poland, Russia, Slovenia and Sweden) the energy consumed in the household sector decreased.

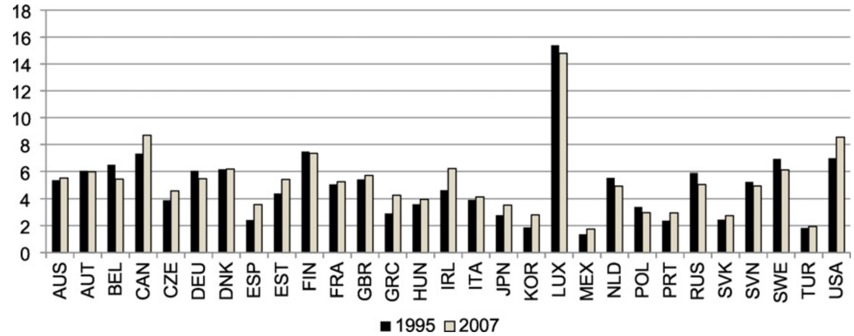

Fig. 4. Exosomatic metabolic rate of the household sector ($EMR_{HH} = ET_{HH}/HA_{HH}$), (MJ/h).

Based on data reported in Table A.3 of the appendix, all the countries considered in this paper, with exception of Great Britain, increased the energy throughput of the paid sector (ET_{PW}). The largest variations have taken place in Ireland (56.4%), Korea (+54.3%), Turkey (+53.3), and Greece (51.4%). Ireland, Korea and Greece, together with Spain, also experienced some of the highest percentage variations of the energy throughput of the household sector (ET_{HH}) (+58.9%, +62.3%, +52.5% and +64.8%, respectively). Industrial development, mechanisation, increasing demand for electrical appliances and transports have been, according to EEA (2015), the main factors responsible for the energy consumption increase. In terms of exosomatic metabolic rate of the paid sector (EMR_{PW}), nineteen countries increased the amount of energy consumed per hour of labour (with exception of Australia, Canada, Spain, France, Great Britain, Mexico, Netherlands, Sweden, USA) (Fig. 5). The largest percentage variations have taken place in Turkey (+65.2%) and Korea (+47.7%). Based on data reported in Table A.5 the appendix, Turkey is the only country that increased the exosomatic metabolic rate in all the twelve economic sectors reported in Table 1. For all of them, the percentage variation of the energy used (ET_{PW}) has been higher than the percentage variation of the human time (HA_{PW}) (Tables A.6 and A.7 of the appendix). Following Velasco-Fernandez et al. (2015), the increase in the exosomatic metabolic rate of the paid sector (EMR_{PW}) can be considered as a proxy of the level of technical capitalisation. An example of that is provided by Korea that, by implementing a set of farm mechanisation plans, largely reduced the number of working hours devoted to the agricultural sector (Choi and Kang, 2016). Based on data reported in Tables A.6 and A.7 of the appendix, between 1995 and 2007 the HA_{PW} of "agriculture, hunting, forestry, mining and quarrying" sector reduced by 35.4% and the energy consumption increased by 46.5%. As a result, the exosomatic metabolic rate of this sector increased (Table A.5 of the appendix).

In terms of labour productivity (ELP_{PW}), all the countries considered in this paper increased the quantity of GDP produced per unit of working hour (Fig. 6). The largest variations have taken place in eastern European countries (Estonia +123.6%; Slovakia +83.2%; Poland +76.3%; Slovenia +64.2%), Turkey (+84.4%) and Korea (+69.7%) (Table A.2 of the appendix). According to different authors (Jorgenson and Timmer, 2011; Campos and Coricelli 2002; Voskoboynikov, 2014; Choi and Kang, 2016), the work productivity increase of these countries can be explained by a set of factors, as for example the large investments in technology and mechanisation, the development of the service sectors, the technological catch up and, for the eastern European countries, the transition from a planned to a market economy and the inclusion in the EU.

The smaller variations have taken place in Spain and Italy where the productivity increase have been largely lower than in the other countries (6.4% in Italy and 7.7% in Spain). According to Gordon and Dew-Becker (2008) the labour market reforms oriented to promote flexibility in the work market, with consequent increase in the availability of temporary and non-expensive workers, have discouraged the investments in productivity and innovation.

4.3. Level N-2 – Economic Sectors Level

In this section, the energy consumption and the human time allocation are analysed at economic sector level, based on the disaggregation reported in Table 1. Three main economic sectors are considered in this section, namely: the agricultural, the industrial and the services sectors. Disaggregated data for the exosomatic metabolic rate of all the activities included in the different sectors are reported in Table A.5 of the appendix. The analysis of the changes that have taken place in different economic sectors can provide important information related to the qualitative (EMR_{PWi}) and quantitative variations (ET_{PWi} and HA_{PWi})

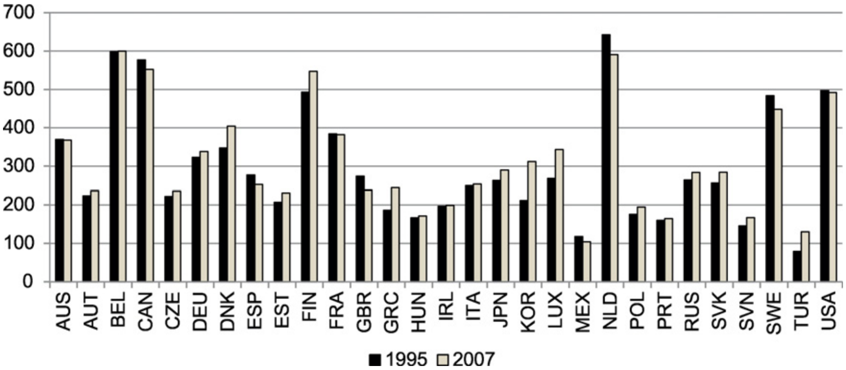

Fig. 5. Exosomatic metabolic rate of the paid sector ($EMR_{PW} = ET_{PW}/HA_{PW}$), (MJ/h).

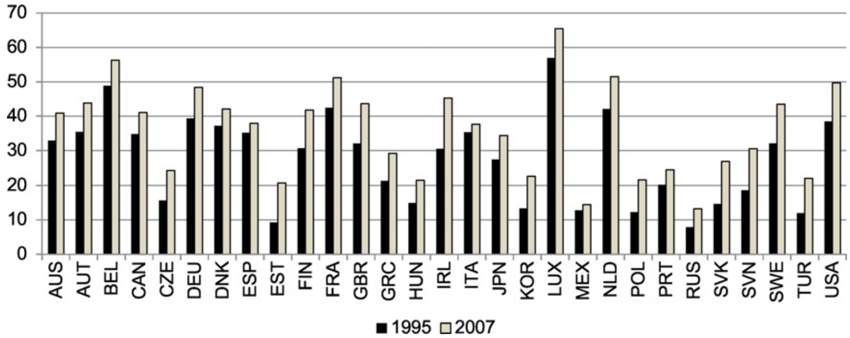

Fig. 6. Labour productivity ($ELP_{PW} = GDP/HA_{PW}$), ($/h).

affecting the size and the characteristics of the metabolic trends of countries (Velasco-Fernandez et al., 2015).

According to data reported in Table 5, in most of the countries considered in this paper (with exception of Belgium, Germany, France, Netherlands and USA) the exosomatic metabolic rate of the agricultural sector (EMR_{PWa}) has increased. Belgium and USA together with Australia have also been the only countries to slightly increase (less than 8%) the human time devoted to the agriculture. In all the other countries, the number of working hours decreased. The largest reductions have taken place in the eastern European countries (Slovakia −60.1%, Estonia −54.5%, Czech Republic −47.6%, Hungary −47.0%), Turkey (−50.2%), Greece (−36.3%) and Korea (−35.4%). Three of them, (Czech Republic, Hungary and Slovakia) also reduced the energy throughput (−36.0%, −18.1% and −41,8%, respectively) (Absolute values are reported in Tables A.8 and A.9 of the appendix). According to EEA (2015), the transition to a more service-oriented economy contributed to reduce the energy and the working time spent in the agricultural sector of these countries. On the contrary, the increasing mechanisation that took place in Turkey, Korea and Estonia, largely contributed to increase the energy consumption of the agricultural sector (Eurostat, 2015; FAO, 2013; OECD, 2008). According to data reported in Table 5, these countries also performed the largest variation of the exosomatic metabolic rate (EMR_{PWa}) (+179.3%, +126.9%, +148.4%, respectively).

Most of the countries also increased the exosomatic metabolic rate of the industrial sector. Denmark, Spain, Estonia, Hungary, Ireland, Mexico and Sweden, have been the only countries to reduce EMR_{PWi} of industry. For all of them, the percentage variation of HA_{PWi} has been higher than the percentage variation of ET_{PWi}. For these countries (ad exception of Denmark), the number of working hours in the industrial and in the service sectors increased, while the number of working hours in the agricultural sector decreased. Ireland, Mexico and Spain also experienced some of the highest percentage of population increase (+21.5%, 16.2%, 13.9%, respectively). All the countries considered in this paper, increased both the energy throughput and the human time allocated to the service sector. In twelve countries, however, the exosomatic metabolic rate of the service sector decreased. For all of them, (namely: Austria, Belgium, Canada, Germany, France, Great Britain, Korea, Mexico, Netherlands, Russia, Slovakia and USA) the percentage variation of the time devoted to this sector has been higher than the energy consumption increase. Belgium and USA recorded the largest exosomatic metabolic rate percentage decrease (−16.2% and −14.9%, respectively) and Denmark and Greece the largest increase (+111.2% and 134.0%, respectively). According to data reported in Tables A.5, A.6 and A.7 of the appendix, the reduction of the energy used, that took place in the financial intermediation (for USA) and in the other community, social and personal service activity sector (for Belgium), has been the main factor responsible for the reduction of the exosomatic metabolic rate of the service sector of Belgium and USA. In Denmark and Greece, the transport sector has been the main sector responsible for the EMR_{PWs} increase. In both countries, the percentage variation of the energy throughput (+219.5% in Denmark and +257.6% in Greece) has been largely higher than the percentage variation of the working hours (+12.9% in Denmark and −16.4% in Greece).

Table 5
Level N-2 - percentage variation of energy throughput (ET), human time (HA) and exosomatic metabolic rate (EMR) between the years 1995 and 2007.

Level N	ET_{PWi}			HA_{PWi}			EMR_{PWi}		
	Agr.	Ind.	Serv.	Agr.	Ind.	Serv.	Agr.	Ind.	Serv.
AUS	74.1	19.1	30.0	1.5	15.9	29.0	71.5	2.8	0.8
AUT	28.4	16.0	19.2	−29.1	−2.8	25.7	81.1	19.3	−5.2
BEL	−19.7	17.1	3.3	2.7	−8.5	23.2	−21.8	28.0	−16.2
CAN	53.1	15.0	13.1	−6.5	14.1	27.8	63.7	0.8	−11.5
CZE	−36.0	2.8	50.0	−47.6	−4.3	7.5	22.2	7.4	39.6
DEU	−40.9	5.0	0.7	−32.4	−20.0	10.0	−12.6	31.2	−8.5
DNK	23.5	−9.1	159.8	−27.2	−3.4	23.0	69.6	−5.9	111.2
ESP	19.7	26.8	57.3	−22.1	49.7	51.1	53.6	−15.3	4.1
EST	12.9	11.3	51.4	−54.5	13.1	11.7	148.4	−1.6	35.6
FIN	−2.4	28.2	44.6	−26.6	17.0	24.0	32.9	9.6	16.6
FRA	−31.7	7.9	8.6	−18.7	−9.0	15.7	−15.9	18.7	−6.2
GBR	50.2	−9.3	2.7	−19.2	−17.3	17.6	85.9	9.7	−12.7
GRC	4.5	31.6	206.7	−36.3	18.6	31.1	64.0	11.0	134.0
HUN	−18.1	4.5	15.4	−47.0	9.2	12.5	54.5	−4.3	2.6
IRL	19.9	38.2	135.5	−24.8	58.8	72.8	59.5	−13.0	36.2
ITA	−8.1	13.2	25.8	−18.6	6.6	19.4	12.9	6.1	5.3
JPN	−17.4	1.3	2.0	−32.9	−19.7	0.6	23.1	26.1	1.4
KOR	46.5	62.0	17.5	−35.4	−19.4	28.0	126.9	100.8	−8.2
MEX	44.4	16.1	50.3	−11.7	49.3	50.7	63.5	−22.3	−0.2
NLD	−12.3	4.6	18.6	−5.7	−3.8	21.6	−7.0	8.7	−2.5
POL	−38.6	6.7	81.5	−43.2	2.3	27.2	8.1	4.3	42.7
PRT	18.4	5.7	73.4	−15.2	−5.6	27.8	39.6	12.0	35.7
RUS	−4.1	9.4	23.4	−18.6	−15.2	27.3	17.8	28.9	−3.1
SVK	−41.8	11.0	4.7	−60.1	−4.0	10.7	45.7	15.7	−5.4
SVN	6.9	14.5	31.5	−43.0	−3.5	26.0	87.7	18.7	4.3
SWE	−3.6	−1.9	14.8	−28.1	0.5	13.5	34.1	−2.4	1.1
TUR	39.2	51.2	71.1	−50.2	14.0	36.4	179.3	32.7	25.4
USA	−11.7	16.1	1.2	7.3	−4.1	19.0	−17.7	21.0	−14.9

4.4. Initial Metabolic Profile of Countries and Development Paths

In this section, the 28 countries considered in this paper are ranked according to the main MuSIASEM variables and indicators reported in Tables 2 and 3. The main objective is to provide an overview of the initial characteristics of countries (for the year 1995) and, based on the results provided above, to identify similarities in the development of metabolic profiles. In Table 6, the ranking of countries is provided for the year 1995 and for the percentage variations that have taken place between the years 1995 and 2007. Countries are ranked from the highest to the lowest values.

Table 6
Ranking of countries in 1995 and percentage variation between the years 1995 and 2007.

Ranking in 1995							Percentage variation between years 1995 and 2007						
THA	TET	GDP	EMRpw	EMRhh	ELPpw	GDP per capita	THA	TET	GDP	EMRpw	EMRhh	ELPpw	GDP per capita
USA	USA	USA	NLD	FIN	BEL	USA	IRL	IRL	EST	TUR	KOR	RUS	EST
RUS	RUS	JPN	BEL	CAN	FRA	CAN	TUR	KOR	IRL	KOR	ESP	EST	IRL
JPN	JPN	DEU	CAN	USA	NLD	NLD	MEX	GRC	SVK	GRC	GRC	TUR	SVK
MEX	DEU	FRA	USA	SWE	DEU	DNK	AUS	TUR	KOR	DNK	IRL	POL	RUS
DEU	FRA	GBR	FIN	BEL	USA	JPN	ESP	ESP	POL	SVN	MEX	MEX	POL
TUR	CAN	ITA	SWE	DNK	DNK	AUS	USA	DNK	RUS	EST	JPN	KOR	SVN
GBR	GBR	RUS	FRA	AUT	AUT	DEU	CAN	FIN	TUR	FIN	PRT	SVK	KOR
FRA	ITA	MEX	AUS	DEU	ITA	AUT	KOR	MEX	SVN	POL	EST	HUN	FIN
ITA	KOR	CAN	DNK	RUS	ESP	BEL	FRA	AUS	FIN	SVK	USA	CZE	CZE
KOR	MEX	ESP	DEU	NLD	CAN	FRA	NLD	CAN	GRC	JPN	CAN	SVN	HUN
ESP	NLD	KOR	ESP	GBR	AUS	ITA	PRT	PRT	MEX	RUS	CZE	PRT	GRC
POL	ESP	TUR	GBR	AUS	SWE	GBR	GRC	EST	ESP	CZE	SVK	GRC	TUR
CAN	AUS	AUS	RUS	SVN	GBR	SWE	BEL	USA	AUS	AUT	HUN	JPN	GBR
AUS	POL	NLD	JPN	FRA	FIN	FIN	ITA	ITA	CZE	DEU	TUR	IRL	SWE
NLD	TUR	POL	SVK	IRL	IRL	IRL	AUT	AUT	GBR	PRT	ITA	FIN	ESP
GRC	BEL	BEL	ITA	EST	JPN	ESP	DNK	SVN	HUN	HUN	GBR	GBR	MEX
CZE	SWE	AUT	AUT	ITA	GRC	GRC	GBR	BEL	USA	ITA	FRA	SWE	AUS
HUN	CZE	SWE	CZE	CZE	PRT	PRT	SWE	SVK	SWE	IRL	AUS	AUS	NLD
BEL	FIN	GRC	KOR	HUN	SVN	SVN	FIN	FRA	CAN	BEL	DNK	CAN	AUT
PRT	GRC	PRT	EST	POL	CZE	CZE	JPN	CZE	NLD	AUS	AUT	ESP	USA
SWE	AUT	CZE	IRL	GRC	HUN	KOR	SVN	HUN	AUT	FRA	FIN	ITA	CAN
AUT	HUN	DNK	GRC	JPN	SVK	HUN	DEU	RUS	PRT	USA	SVN	AUT	PRT
SVK	DNK	HUN	POL	SVK	KOR	SVK	SVK	POL	BEL	CAN	DEU	DNK	BEL
DNK	PRT	FIN	HUN	ESP	MEX	MEX	CZE	NLD	FRA	SWE	NLD	USA	DNK
FIN	SVK	IRL	PRT	PRT	POL	POL	POL	JPN	DNK	NLD	SWE	DEU	FRA
IRL	IRL	SVK	SVN	KOR	TUR	TUR	HUN	DEU	DEU	ESP	POL	NLD	DEU
SVN	SVN	SVN	MEX	TUR	EST	EST	RUS	SWE	ITA	MEX	RUS	FRA	ITA
EST	EST	EST	TUR	MEX	RUS	RUS	EST	GBR	JPN	GBR	BEL	BEL	JPN

4.4.1. 1995 Metabolic Profiles

- According to data reported in Table 6, the countries with the highest GDP also had the highest total energy throughput (TET) and total human time (THA). USA, Russia, Japan, Mexico, Germany, France, Great Britain and Italy ranked in the top ten countries for all the three MuSIASEM variables reported in Table 2. In a similar way, the countries with the lowest level of GDP also had the lowest level of TET and THA (namely: Estonia, Slovenia, Ireland and Slovakia).
- Eight of the top ten countries that in 1995 had the highest exosomatic metabolic rate of the paid sector (EMR_{PW}), also had the highest exosomatic metabolic rate of the household sector (EMR_{HH}) (namely: Netherlands, Belgium, Canada, USA, Denmark, Germany, Finland and Sweden).
- Six of them, also had some of the largest values of labour productivity (ELP_{PW}) and GDP per capita (namely: Belgium, Netherlands, Germany, USA, Denmark and Canada).
- In a similar way, seven of the ten countries with the lowest exosomatic metabolic rate of the paid sector (ELP_{PW}) also had the lowest exosomatic metabolic rate of the household sector (ELP_{HH}) (namely: Turkey, Mexico, Portugal, Hungary, Poland, Greece and Korea).
- All of them, together with Estonia Russia, Slovakia, Check Republic and Slovenia, also had some of the smallest values of labour productivity (ELP_{PW}) and GDP per capita.

4.4.2. 1995–2007 Metabolic Profile Developments

- The countries with the lowest level of GDP, had some of the highest GDP percentage variations (namely: Estonia, Ireland, and Slovakia). Ireland also performed the highest energy throughput percentage increases (TET). On the contrary, Estonia and Slovakia ranked twelve and eighteen in terms of TET variation. As reported in Table A.2 of the appendix, these two countries had the largest energy efficiency (EEI) increase.
- Some of the countries that in 1995 had some of the lowest level of exosomatic metabolic rate of the paid sector, performed some of the largest EMR_{PW} percentage increases (namely: Turkey, Slovenia, Greece, Estonia, Korea and Poland). On the contrary, six of the top ten countries that in 1995 had the highest values of EMR_{PW}, performed some of the smallest increases (namely: Netherlands, Belgium, Canada, USA, Sweden, Austria and France).
- Six of the eight countries with the lowest level of exosomatic metabolic rate of the household sectors (EMR_{HH}) performed the largest percentage increases (namely: Mexico, Korea, Portugal, Spain, Japan and Greece). On the contrary, seven of the ten countries with the highest level of EMR_{HH} performed the smallest percentage variations (namely: Finland, Sweden, Belgium, Denmark, Australia, Germany and Netherlands).
- Eight of the eleven countries with the lowest level of labour productivity (ELP) and per capita GDP had some of the largest percentage increase (namely: Russia, Estonia, Poland, Korea, Slovakia, Hungary, Czech Republic and Slovenia). On the contrary, seven of the ten countries that in 1995 had the highest level of labour productivity and per capita GDP, performed some of the lowest percentage increase (namely: Netherlands, Belgium, Canada, USA, France, Denmark and Germany).

Based on data reported above, metabolic patterns can be identified between the following groups of countries: 1) the western European countries (excluding Ireland), together with USA, Japan and Canada 2) the eastern European countries, together with Turkey, Ireland and Korea.

The first group of countries generally had the highest initial values of metabolic variables and indicators. However, between the years 1995 and 2007, most of them performed the lowest percentage increases. On the contrary, the eastern European countries, together with Turkey, Ireland and Korea, in spite of having some of the smallest metabolic profiles in 1995, performed some of the largest percentage increases. In particular:

- The eastern European countries, together with Russia performed the largest energy efficiency increases.
- The eastern European countries, together with Korea, Russia, Ireland and Turkey had the largest GDP and GDP per capita increases.

- The eastern European countries, together with Turkey and Russia had the largest labour productivity increases.
- Three eastern European countries (namely: Czech Republic, Slovakia and Poland), together with Turkey and Korea increased the dependency ratio.
- The eastern European countries, together with Turkey and Korea had the largest reduction in the human time devoted to agriculture.

Mexico is performing as an outliner and cannot be included in the two group of countries reported above. In particular, in 1995 it ranked in the top half for the metabolic variables and in the bottom half for the metabolic indicators. In terms of percentage variations, it ranked in the first top half for THA, TET, GDP, EMR_{HH}, ELP_{PW} and in the bottom half for EMR_{PW}, and GDP per capita.

5. Future Developments and Limitations

In this paper the metabolic profile of 28 world countries have been investigated. As reported above, the selection of countries has been mainly driven by data availability. Both European and non-European countries have been considered in the analysis, however some of the fastest growing areas, as for example India, China and Brazil have not been included because data availability was not covering the entire time period considered in this paper. These countries have been previously investigated in other studies (Ramos-Martin et al., 2007; Velasco-Fernandez et al., 2015). Another gap is related to the lack of consistent data for Middle East countries, as Qatar, Dubai or Saudi Arabia. During the last decade those countries massively changed the metabolic profile by increasing the use of fossil fuel resources. The rapid economic growth and the large migration inflow of workers from other Asian countries largely contributed to increase consumption and human time availability. The analysis of the exosomatic metabolic profile of these countries would be particularly interesting to investigate. When data will be available, additional analysis could also be oriented to investigate the impacts that the global economic crisis generated on the metabolic trend of developed and developing countries.

6. Conclusions

In this article, the metabolic profile of 28 world countries have been analysed. The main conclusions can be summarised as follow:

6.1. Level N

- Between the years 1995 and 2007, the gross domestic product (GDP) increased for all the countries considered in this paper. The largest percentage variations have taken place in Ireland, Korea, Russia, Turkey and in the Eastern European countries that during the period considered joined the EU.
- The total energy throughput (TET) increased for all the countries considered in this paper, with the exception of Great Britain and Sweden.
- Energy consumption grew slower than GDP. Russia, Great Britain, Sweden and the eastern European countries that joined the EU had the largest energy efficiency increase.
- The percentage variation of the total energy throughput (TET) has been generally higher than the percentage variation of the total human time (THA). As a consequence, the per capita energy consumption increased.

6.2. Level N-1

- The percentage increase of the number of hours devoted to the paid working activities (HA_{PW}) has increased more than the percentage variation of the number of number of hours spent in the household sectors (HA_{HH}). The only exceptions are Czech Republic, Germany, Japan, Korea, Poland, Slovakia and Turkey.
- The countries reported above, are also the only countries that increased the dependency ratio of non-working and unemployed population.
- Twenty-one countries increased the energy throughput (ET_{HH}) of the household sector, and nineteen of them increased the energy used per unit of time (EMR_{HH}). The higher energy consumption is usually associated with more energy services and home appliances and can be considered as a proxy of the material standard of living.
- All the countries considered in this paper, with exception of Great Britain, increased the energy throughput of the paid sector (ET_{PW}). The largest percentage increases have taken place in Ireland, Korea, Turkey and Greece.
- Nineteen of the considered countries also increased the exosomatic metabolic rate of the paid sector (EMR_{PW}). The largest percentage variations have taken place in Turkey and Korea. The increase in the exosomatic metabolic rate is usually considered as a proxy of an increasing level of technical capitalisation.
- All the countries increased the quantity of GDP produced per unit of working hour. Eastern European countries, Turkey and Korea had the largest labour productivity increase.

6.3. Level N-2

- In most of the countries, with exception of Belgium, Germany, France, Netherlands and USA, the exosomatic metabolic rate of the agricultural sector (EMR_{PWa}) has increased.
- Belgium, USA and Australia have been the only countries to slightly increase the human time devoted to agriculture. The largest reductions have taken place in the eastern European countries, Turkey, Greece and Korea.
- The largest increase in the exosomatic metabolic rate of the agricultural sector have taken place in Turkey, Korea and Estonia. The increasing mechanisation of the agricultural sector and the replacement of manual labour that has taken place during the period considered in this paper has been the main factor influencing the EMR_{PWa} increase.
- Denmark, Spain, Estonia, Hungary, Ireland, Mexico and Sweden, have been the only countries to reduce the exosomatic metabolic rate of the industrial sector (EMR_{PWi}).
- All the countries considered in this paper, increased both the energy throughput and the human time allocated to the service sector. In twelve countries, however, the exosomatic metabolic rate of the service sector (EMR_{PWs}) decreased. For all of them, (namely: Austria, Belgium, Canada, Germany, France, Great Britain, Korea, Mexico, Netherlands, Russia, Slovakia and USA) the percentage variation of the time devoted to this sector has been higher than the energy consumption increase.
- None of the considered countries decrease the exosomatic metabolic rate in all the three economic sectors.
- When comparing the initial and the development of the metabolic profile, two main groups of countries can be identified: 1) the western European countries, together with USA, Canada and Japan that generally had the highest initial values of the metabolic variables and indicators considered in this paper but the lowest percentage variations, and 2) the eastern European countries, together with Ireland, Korea, Russia and Turkey that had some of the smallest initial values but some of the highest percentage increases.

In spite of the differences existing between countries, the increasing energy throughput and per-capita consumption, contributed to change the metabolic profile of the countries considered in this paper. By considering the development of societies, at different scales and periods of time, the MuSIASEM approach can be useful to support policies in the design of sustainable strategies.

Appendix A

Table A.1
Level N - variables.

Level N	GDP (million $)			THA (million hours)			TET (TJ)		
	1995	2007	%Δ	1995	2007	%Δ	1995	2007	%Δ
AUS	502,646	773,752	53.9	157,724	182,453	15.7	6,405,848	7,865,362	22.8
AUT	217,988	297,455	36.5	69,627	72,666	4.4	1,760,150	1,999,229	13.6
BEL	270,714	356,279	31.6	88,798	93,081	4.8	3,856,037	4,270,650	10.8
CAN	841,464	1,216,807	44.6	256,688	288,445	12.4	15,645,683	18,609,611	18.9
CZE	162,615	246,299	51.5	90,497	90,427	−0.1	2,616,111	2,764,719	5.7
DEU	2,271,421	2,747,927	21.0	715,500	720,653	0.7	22,615,713	22,849,823	1.0
DNK	146,819	188,940	28.7	45,844	47,842	4.4	1,629,797	2,083,408	27.8
ESP	827,749	1,280,266	54.7	347,938	396,267	13.9	7,299,677	9,820,366	34.5
EST	11,404	26,362	131.2	12,585	11,759	−6.6	304,409	350,553	15.2
FIN	111,898	177,176	58.3	44,737	46,340	3.6	2,104,797	2,630,539	25.0
FRA	1,502,840	1,950,171	29.8	506,716	542,814	7.1	15,991,494	17,220,816	7.7
GBR	1,443,222	2,132,878	47.8	508,299	529,821	4.2	14,859,358	14,414,996	−3.0
GRC	187,215	295,341	57.8	93,157	97,788	5.0	1,878,234	2,846,047	51.5
HUN	120,752	178,087	47.5	90,482	88,089	−2.6	1,643,244	1,733,984	5.5
IRL	77,829	178,579	129.5	31,547	38,332	21.5	635,826	997,550	56.9
ITA	1,436,039	1,722,353	19.9	497,956	520,128	4.5	11,925,212	13,558,942	13.7
JPN	3,515,513	4,042,140	15.0	1,099,993	1,119,274	1.8	36,451,922	37,643,953	3.3
KOR	683,750	1,212,435	77.3	395,015	425,715	7.8	11,454,080	17,726,426	54.8
MEX	924,217	1,432,980	55.0	827,735	961,738	16.2	9,537,518	11,820,099	23.9
NLD	440,027	615,570	39.9	135,421	143,504	6.0	7,407,439	7,722,453	4.3
POL	347,245	596,759	71.9	335,289	333,896	−0.4	6,004,582	6,277,681	4.5
PRT	175,740	234,105	33.2	87,829	92,356	5.2	1,577,803	1,822,695	15.5
RUS	1,163,952	1,991,696	71.1	1,299,774	1,250,972	−3.8	45,750,349	48,268,093	5.5
SVK	58,019	104,312	79.8	46,971	47,082	0.2	1,119,590	1,221,955	9.1
SVN	31,790	53,169	67.3	17,411	17,690	1.6	331,407	370,209	11.7
SWE	217,501	318,191	46.3	77,324	80,137	3.6	3,766,380	3,725,935	−1.1
TUR	510,906	874,086	71.1	523,463	614,585	17.4	4,243,044	6,276,311	47.9
USA	9,349,639	13,685,243	46.4	2,332,599	2,638,785	13.1	135,268,941	155,597,146	15.0

Table A.2
Level N - indicators.

Level N	EEI (TET/GDP) (TJ/million $)			ELPpw (GDP/HA) (million $/million hours)			EMRsa (TET/THA) (TJ/million hours)		
	1995	2007	%Δ	1995	2007	%Δ	1995	2007	%Δ
AUS	12.7	10.2	−20.2	32.93	40.9	24.2	40.6	43.1	6.1
AUT	8.1	6.7	−16.8	35.45	43.8	23.6	25.3	27.5	8.8
BEL	14.2	12.0	−15.8	48.89	56.3	15.1	43.4	45.9	5.7
CAN	18.6	15.3	−17.7	34.82	41.1	17.9	61.0	64.5	5.8
CZE	16.1	11.2	−30.2	15.66	24.2	54.6	28.9	30.6	5.8
DEU	10.0	8.3	−16.5	39.38	48.4	22.9	31.6	31.7	0.3
DNK	11.1	11.0	−0.7	37.20	42.1	13.1	35.6	43.5	22.5
ESP	8.8	7.7	−13.0	35.20	37.9	7.7	21.0	24.8	18.1
EST	26.7	13.3	−50.2	9.27	20.7	123.6	24.2	29.8	23.2
FIN	18.8	14.8	−21.1	30.69	41.8	36.1	47.0	56.8	20.7
FRA	10.6	8.8	−17.0	42.45	51.2	20.6	31.6	31.7	0.5
GBR	10.3	6.8	−34.4	32.08	43.6	36.0	29.2	27.2	−6.9
GRC	10.0	9.6	−3.9	21.35	29.2	36.7	20.2	29.1	44.4
HUN	13.6	9.7	−28.5	14.95	21.5	44.0	18.2	19.7	8.4
IRL	8.2	5.6	−31.6	30.55	45.3	48.2	20.2	26.0	29.1
ITA	8.3	7.9	−5.2	35.37	37.6	6.4	23.9	26.1	8.9
JPN	10.4	9.3	−10.2	27.42	34.4	25.3	33.1	33.6	1.5
KOR	16.8	14.6	−12.7	13.36	22.7	69.7	29.0	41.6	43.6
MEX	10.3	8.2	−20.1	12.80	14.4	12.8	11.5	12.3	6.7
NLD	16.8	12.5	−25.5	42.13	51.5	22.3	54.7	53.8	−1.6
POL	17.3	10.5	−39.2	12.27	21.6	76.3	17.9	18.8	5.0
PRT	9.0	7.8	−13.3	20.22	24.4	20.8	18.0	19.7	9.9
RUS	39.3	24.2	−38.3	7.89	13.2	67.8	35.2	38.6	9.6
SVK	19.3	11.7	−39.3	14.66	26.9	83.2	23.8	26.0	8.9
SVN	10.4	7.0	−33.2	18.60	30.6	64.2	19.0	20.9	9.9
SWE	17.3	11.7	−32.4	32.11	43.5	35.4	48.7	46.5	−4.5
TUR	8.3	7.2	−13.5	11.97	22.1	84.4	8.1	10.2	26.0
USA	14.5	11.4	−21.4	38.51	49.7	29.1	58.0	59.0	1.7

Table A.3
Level N-1 – variables and indicators.

Level N-1	HA_{PW} (million hours)			HA_{HH} (million hours)			ET_{PW} (TJ)		
	1995	2007	%Δ	1995	2007	%Δ	1995	2007	%Δ
AUS	15,263	18,920	24.0	142,461	163,534	14.8	5,639,431	6,960,107	23.4
AUT	6149	6789	10.4	63,478	65,877	3.8	1,376,154	1,605,915	16.7
BEL	5537	6331	14.3	83,261	86,750	4.2	3,314,811	3,797,204	14.6
CAN	24,163	29,625	22.6	232,525	258,820	11.3	13,942,889	16,361,637	17.3
CZE	10,385	10,175	−2.0	80,112	80,252	0.2	2,304,499	2,396,910	4.0
DEU	57,679	56,788	−1.5	657,821	663,865	0.9	18,638,099	19,205,276	3.0
DNK	3947	4490	13.8	41,898	43,352	3.5	1,371,712	1,815,767	32.4
ESP	23,514	33,757	43.6	324,423	362,510	11.7	6,515,906	8,528,911	30.9
EST	1230	1272	3.4	11,355	10,487	−7.6	254,511	293,596	15.4
FIN	3646	4242	16.4	41,092	42,098	2.4	1,797,575	2,321,522	29.1
FRA	35,398	38,095	7.6	471,317	504,719	7.1	13,599,880	14,563,174	7.1
GBR	44,994	48,898	8.7	463,305	480,922	3.8	12,339,367	11,658,408	−5.5
GRC	8769	10,117	15.4	84,388	87,671	3.9	1,633,444	2,472,640	51.4
HUN	8080	8277	2.4	82,402	79,811	−3.1	1,347,191	1,418,636	5.3
IRL	2548	3944	54.8	28,999	34,388	18.6	501,409	784,006	56.4
ITA	40,600	45,751	12.7	457,356	474,377	3.7	10,132,619	11,596,025	14.4
JPN	128,222	117,623	−8.3	971,771	1001,65	13.1	33,758,939	34,115,635	1.1
KOR	51,162	53,455	4.5	343,852	372,260	8.3	10,812,867	16,685,429	54.3
MEX	72,201	99,244	37.5	755,535	862,493	14.2	8,510,128	10,319,725	21.3
NLD	10,445	11,950	14.4	124,976	131,554	5.3	6,713,273	7,060,313	5.2
POL	28,305	27,586	−2.5	306,984	306,310	−0.2	4,965,812	5,369,933	8.1
PRT	8693	9589	10.3	79,136	82,767	4.6	1,390,466	1,578,748	13.5
RUS	147,480	150,394	2.0	1,152,294	1,100,577	−4.5	38,949,024	42,701,830	9.6
SVK	3957	3884	−1.8	43,015	43,198	0.4	1,014,480	1,103,878	8.8
SVN	1709	1740	1.8	15,702	15,950	1.6	248,893	291,224	17.0
SWE	6773	7319	8.1	70,551	72,818	3.2	3,277,103	3,280,782	0.1
TUR	42,696	39,623	−7.2	480,767	574,962	19.6	3,367,185	5,160,938	53.3
USA	242,776	275,294	13.4	2,089,823	2,363,49	113.1	120,676,906	135,398,205	12.2

Table A.4
Level N-1 - indicators.

Level N-1	ET_{HH} (TJ)			EMR_{pw} (MJ/h)			EMR_{HH} (MJ/h)			HApw/THA (million hours)
	1995	2007	%Δ	1995	2007	%Δ	1995	2007	%Δ	%Δ 1995–2007
AUS	766,417	905,255	18.1	369	368	−0.4	5.4	5.5	2.9	7.16
AUT	383,996	393,314	2.4	224	237	5.7	6.0	6.0	−1.3	5.78
BEL	541,226	473,446	−12.5	599	600	0.2	6.5	5.5	−16.0	9.08
CAN	1702,795	2,247,973	32.0	577	552	−4.3	7.3	8.7	18.6	9.11
CZE	311,612	367,809	18.0	222	236	6.2	3.9	4.6	17.8	−1.95
DEU	3,977,614	3,644,547	−8.4	323	338	4.7	6.0	5.5	−9.2	−2.25
DNK	258,085	267,641	3.7	348	404	16.3	6.2	6.2	0.2	9.03
ESP	783,771	1,291,456	64.8	277	253	−8.8	2.4	3.6	47.5	26.05
EST	49,898	56,957	14.1	207	231	11.6	4.4	5.4	23.6	10.64
FIN	307,222	309,017	0.6	493	547	11.0	7.5	7.3	−1.8	12.33
FRA	2,391,614	2,657,643	11.1	384	382	−0.5	5.1	5.3	3.8	0.46
GBR	2,519,991	2,756,588	9.4	274	238	−13.1	5.4	5.7	5.4	4.26
GRC	244,790	373,407	52.5	186	244	31.2	2.9	4.3	46.8	9.91
HUN	296,053	315,348	6.5	167	171	2.8	3.6	4.0	10.0	5.23
IRL	134,417	213,545	58.9	197	199	1.0	4.6	6.2	34.0	27.39
ITA	1,792,593	1,962,917	9.5	250	253	1.6	3.9	4.1	5.6	7.88
JPN	2,692,983	3,528,318	31.0	263	290	10.2	2.8	3.5	27.1	−9.85
KOR	641,213	1,040,997	62.3	211	312	47.7	1.9	2.8	50.0	−3.05
MEX	1,027,389	1,500,375	46.0	118	104	−11.8	1.4	1.7	27.9	18.30
NLD	694,166	649,614	−6.4	643	591	−8.1	5.6	4.9	−11.1	7.96
POL	1,038769	907,748	−12.6	175	195	11.0	3.4	3.0	−12.4	−2.13
PRT	187,338	243,947	30.2	160	165	2.9	2.4	2.9	24.5	4.89
RUS	6,801,325	5,566,263	−18.2	264	284	7.5	5.9	5.1	−14.3	5.95
SVK	105,109	118,077	12.3	256	284	10.8	2.4	2.7	11.9	−2.07
SVN	82,513	78,985	−4.3	146	167	14.9	5.3	5.0	−5.8	0.24
SWE	489,277	445,152	−9.0	484	448	−7.4	6.9	6.1	−11.9	4.28
TUR	875,859	1,115,373	27.3	79	130	65.2	1.8	1.9	6.5	−20.96
USA	14,592,034	20,198,941	38.4	497	492	−1.1	7.0	8.5	22.4	0.24

Table A.5
Level N-2: exosomatic metabolic rate of paid sectors (EMR_{PWi}) - percentage variations between the years 1995 and 2007.

	A + B + C	D	E	F	G	H	I	J	L	M	N	O + P + Q	Etpw
AUS	71.5	4.3	31.3	−32.1	28.8	−3.9	−1.7	6.3	3.4	44.4	3.5	0.0	−0.4
AUT	81.1	12.1	49.4	92.9	−32.5	−22.5	28.3	−37.0	−3.9	−15.3	22.7	−15.6	5.7
BEL	−21.8	36.1	29.9	4.0	−11.8	19.9	−7.6	−18.9	4.0	64.0	−5.7	−19.1	0.2
CAN	63.7	16.6	11.9	−21.5	−13.3	−24.5	−15.5	−18.8	3.1	−0.4	−16.4	80.7	−4.3
CZE	22.2	−11.6	88.8	−18.6	71.0	−35.6	83.8	−17.7	30.5	94.8	−11.7	113.3	6.2
DEU	−12.6	21.9	53.1	−1.7	−18.2	1.3	16.3	−12.3	−5.7	−21.4	3.8	−16.4	4.7
DNK	69.6	0.2	24.0	−4.0	−6.6	−15.2	182.9	−10.7	−9.6	4.3	0.6	−42.3	16.3
ESP	53.6	−2.0	51.6	−30.1	56.8	−2.4	−1.1	9.7	58.3	33.6	10.8	0.0	−8.8
EST	148.4	2.3	83.9	−38.9	142.0	248.3	38.6	51.4	29.6	9.5	6.4	0.0	11.6
FIN	32.9	17.1	73.2	0.2	19.7	36.9	29.3	4.5	27.2	1.5	−15.2	16.7	11.0
FRA	−15.9	20.0	38.5	7.0	9.2	16.6	−28.0	1.1	77.2	41.0	−1.1	7.0	−0.5
GBR	85.9	23.8	28.6	−27.6	−20.6	−14.3	2.6	−18.8	−41.3	−26.1	6.1	68.5	−13.1
GRC	64.0	22.8	84.8	−1.4	122.4	21.2	327.9	28.1	38.0	−22.3	45.1	−35.2	31.2
HUN	54.5	−1.1	70.1	−39.3	−17.9	−15.4	55.8	−42.4	2.6	30.7	14.5	0.0	2.8
IRL	59.5	28.2	27.7	−11.0	27.3	131.6	19.7	100.0	−29.5	25.3	115.7	189.6	1.0
ITA	12.9	6.3	78.6	−13.7	30.8	12.4	6.7	−6.6	4.6	−10.4	−9.7	12.0	1.6
JPN	23.1	19.9	16.3	−9.7	24.6	46.5	3.9	−12.5	−13.0	−18.5	−8.4	0.0	10.2
KOR	126.9	87.7	87.0	49.6	4.3	−73.3	9.2	24.0	−22.2	58.9	92.0	0.0	47.7
MEX	63.5	−18.4	19.7	3.9	6.8	−2.3	−2.8	−23.3	9.0	−1.7	10.4	−10.2	−11.8
NLD	−7.0	16.0	58.2	−21.9	−16.2	8.9	20.8	−3.1	15.4	−9.6	−17.3	40.0	−8.1
POL	8.1	10.8	32.8	75.4	−18.3	−11.3	88.1	60.2	−24.7	29.1	−17.3	45.5	11.0
PRT	39.6	23.5	55.4	−14.8	57.0	16.1	36.2	−2.7	70.7	56.9	37.4	373.0	2.9
RUS	17.8	52.1	−12.7	−41.4	23.1	13.3	12.3	22.8	0.1	−13.5	−14.2	0.0	7.5
SVK	45.7	34.9	21.0	−54.3	−72.8	−53.1	218.0	−53.6	−10.0	7.6	12.0	0.0	10.8
SVN	87.7	10.7	40.8	−10.6	−1.5	−14.7	54.9	−64.9	30.7	−17.9	−21.3	30.3	14.9
SWE	34.1	3.5	−7.2	−10.6	−23.5	15.5	28.0	−25.9	−0.7	9.1	12.8	−59.7	−7.4
TUR	179.3	0.5	190.1	71.0	101.2	124.1	8.4	3.3	694.0	161.7	363.7	147.2	65.2
USA	−17.7	37.0	47.6	−27.1	−20.8	−9.9	21.0	−13.9	−29.2	10.7	−20.0	−32.3	−1.1

Table A.6
Level N-2: energy throughput of paid sectors (ET_{PW}) - percentage variations between the years 1995 and 2007.

	A + B + C	D	E	F	G	H	I	J	L	M	N	O + P + Q	Etpw
AUS	74.1	−3.6	56.9	7.1	46.3	24.3	18.8	54.0	24.0	79.2	48.8	46.6	23.4
AUT	28.4	9.4	28.4	88.7	−25.7	−1.5	34.0	6.2	−1.9	14.8	65.3	10.1	16.7
BEL	−19.7	17.5	16.5	12.0	−7.8	26.2	−3.3	33.6	20.0	81.4	24.1	−28.3	14.6
CAN	53.1	16.0	13.0	15.8	6.1	−5.8	7.2	19.8	5.7	15.8	18.9	67.1	17.3
CZE	−36.0	−12.4	24.1	−25.5	65.5	−25.7	83.2	8.8	33.2	102.6	−4.3	105.2	4.0
DEU	−40.9	3.4	9.4	−31.9	−21.9	17.9	7.9	24.9	−21.0	−9.9	21.8	0.6	3.0
DNK	23.5	−15.8	−2.5	32.1	8.1	10.9	219.5	48.3	−11.1	7.4	23.2	3.2	32.4
ESP	19.7	15.2	54.4	48.6	122.9	53.5	38.5	100.3	93.1	87.1	81.3	81.3	30.9
EST	12.9	−10.2	21.4	47.0	151.9	341.0	28.4	130.6	45.5	17.8	24.2	132.3	15.4
FIN	−2.4	23.7	35.6	52.2	46.2	86.7	42.9	62.0	37.5	9.2	5.6	87.1	29.1
FRA	−31.7	−2.2	20.2	21.2	17.0	31.9	−19.6	35.2	71.1	51.3	20.5	36.0	7.1
GBR	50.2	−15.1	2.6	−15.1	−14.1	11.5	2.0	10.7	−43.2	−16.2	41.3	92.0	−5.5
GRC	4.5	30.2	34.0	47.4	189.1	57.8	257.6	130.6	66.6	19.5	98.2	22.7	51.4
HUN	−18.1	1.6	9.2	−6.5	−0.2	6.0	44.0	−5.0	3.1	26.7	18.9	3.6	5.3
IRL	19.9	40.7	30.2	157.6	96.9	266.7	136.2	339.2	−6.2	85.5	305.4	177.4	56.4
ITA	−8.1	4.7	42.6	18.2	33.0	46.5	24.4	52.8	−10.4	−3.4	10.2	50.7	14.4
JPN	−17.4	−2.3	12.2	−30.2	−3.4	32.7	−2.5	3.8	21.7	−17.9	2.4	1.9	1.1
KOR	46.5	45.6	126.3	30.8	−9.3	−65.8	32.8	107.2	−8.9	136.0	263.3	110.1	54.3
MEX	44.4	4.5	49.2	108.7	62.4	35.8	48.4	127.3	27.8	27.0	43.3	28.5	21.3
NLD	−12.3	2.7	16.9	−9.2	−8.2	17.2	32.7	39.8	11.0	6.4	10.5	44.8	5.2
POL	−38.6	10.1	0.6	112.4	−9.6	8.9	112.0	148.8	97.6	82.1	−12.6	78.4	8.1
PRT	18.4	2.2	18.0	4.0	87.3	52.6	58.7	62.3	80.1	92.7	105.7	394.3	13.5
RUS	−4.1	16.4	4.4	−43.6	134.7	105.2	14.8	23.1	76.8	−15.1	−3.5	2.8	9.6
SWK	−41.8	24.3	−4.7	−47.9	−56.9	−43.5	162.2	−28.7	−7.7	−22.4	−8.5	24.2	8.8
SVN	6.9	−4.9	26.4	31.8	−0.8	−3.7	76.3	−39.1	89.6	4.1	−3.5	60.9	17.0
SWE	−3.6	−3.8	0.1	11.7	−17.5	38.6	26.8	6.2	−15.5	23.2	30.6	1.0	0.1
TUR	39.2	25.0	129.7	56.6	201.3	319.2	29.2	108.3	692.1	255.9	434.6	243.9	53.3
USA	−11.7	12.2	24.0	−0.5	−13.4	13.7	29.4	9.6	−21.1	53.5	2.8	−30.6	12.2

Table A.7
Level N-2: total hours worked per persons engaged (HA_{PW}) - percentage variations between the years 1995 and 2007.

	A + B + C	D	E	F	G	H	I	J	L	M	N	O + P + Q	Etpw
AUS	1.5	−7.6	19.5	57.6	13.5	29.3	20.8	44.9	19.8	24.2	43.9	0.0	24.0
AUT	−29.1	−2.4	−14.1	−2.2	10.1	27.1	4.5	68.4	2.1	35.4	34.7	30.5	10.4
BEL	2.7	−13.7	−10.3	7.7	4.5	5.2	4.6	64.8	15.4	10.6	31.6	−11.5	14.3
CAN	−6.5	−0.5	1.0	47.6	22.3	24.7	26.9	47.6	2.5	16.3	42.2	−7.5	22.6
CZE	−47.6	−0.8	−34.3	−8.4	−3.2	15.5	−0.4	32.3	2.1	4.0	8.4	−3.8	−2.0
DEU	−32.4	−15.2	−28.6	−30.7	−4.6	16.4	−7.2	42.5	−16.2	14.6	17.4	20.3	−1.5
DNK	−27.2	−16.0	−21.4	37.6	15.7	30.8	12.9	66.0	−1.7	2.9	22.5	78.7	13.8
ESP	−22.1	17.5	1.8	112.6	42.1	57.4	40.0	82.6	21.9	40.1	63.6	0.0	43.6
EST	−54.5	−12.2	−34.0	140.7	4.1	26.6	−7.4	52.3	12.3	7.5	16.7	0.0	3.4
FIN	−26.6	5.6	−21.7	52.0	22.1	36.3	10.5	54.9	8.1	7.6	24.6	60.3	16.4
FRA	−18.7	−18.5	−13.2	13.2	7.2	13.1	11.7	33.7	−3.5	7.3	21.9	27.1	7.6
GBR	−19.2	−31.5	−20.2	17.2	8.1	30.1	−0.6	36.3	−3.2	13.5	33.2	13.9	8.7
GRC	−36.3	6.0	−27.5	49.4	30.0	30.2	−16.4	80.0	20.8	53.7	36.6	89.4	15.4
HUN	−47.0	2.7	−35.8	54.0	21.7	25.4	−7.6	64.9	0.5	−3.1	3.9	0.0	2.4
IRL	−24.8	9.8	1.9	189.3	54.7	58.4	97.3	119.6	33.0	48.1	87.9	−4.2	54.8
ITA	−18.6	−1.5	−20.2	37.0	1.7	30.4	16.6	63.6	−14.3	7.8	22.0	34.6	12.7
JPN	−32.9	−18.6	−3.6	−22.7	−22.4	−9.4	−6.2	18.6	40.0	0.7	11.8	0.0	−8.3
KOR	−35.4	−22.4	21.0	−12.6	−13.0	28.3	21.6	67.0	17.1	48.5	89.3	0.0	4.5
MEX	−11.7	28.1	24.7	100.9	52.1	39.0	52.6	196.3	17.3	29.2	29.8	43.1	37.5
NLD	−5.7	−11.5	−26.1	16.2	9.5	7.6	9.8	44.3	−3.8	17.7	33.6	3.5	14.4
POL	−43.2	−0.7	−24.3	21.1	10.7	22.8	12.7	55.3	162.5	41.0	5.6	22.6	−2.5
PRT	−15.2	−17.3	−24.1	22.0	19.3	31.4	16.5	66.8	5.5	22.8	49.7	4.5	10.3
RUS	−18.6	−23.5	19.5	−3.6	90.7	81.1	2.2	0.2	76.5	−2.0	12.6	0.0	2.0
SWK	−60.1	−7.8	−21.2	13.8	58.7	20.5	−17.5	53.5	2.6	−27.9	−18.3	0.0	−1.8
SVN	−43.0	−14.1	−10.2	47.5	0.7	12.8	13.8	73.6	45.0	26.8	22.7	23.5	1.8
SWE	−28.1	−7.0	7.9	24.9	7.9	20.0	−0.9	43.3	−14.9	12.9	15.8	150.9	8.1
TUR	−50.2	24.4	−20.8	−8.4	49.7	87.1	19.2	101.6	−0.2	36.0	15.3	39.1	−7.2
USA	7.3	−18.1	−16.0	36.6	9.3	26.2	7.0	27.3	11.5	38.7	28.6	2.5	13.4

Table A.8
Level N-2: energy throughput of economic sectors (ET_{PWi}) – absolute values (TJ).

1995	Agr.	Ind.	Serv.	2007	Agr.	Ind.	Serv.
AUS	293,841	4,577,955	767,636	AUS	511,671	5,450,441	997,996
AUT	33,561	1,164,516	178,077	AUT	43,105	1,350,562	212,248
BEL	56,334	2,794,738	463,740	BEL	45,235	3,272,992	478,976
CAN	989,362	10,386,693	2,566,834	CAN	1,514,636	11,944,071	2,902,930
CZE	139,472	1,992,556	172,472	CZE	89,307	2,048,895	258,708
DEU	575,926	15,707,533	2,354,640	DEU	340,390	16,493,632	2,371,254
DNK	66,987	980,896	323,829	DNK	82,717	891,733	841,316
ESP	138,236	5,478,154	899,516	ESP	165,465	6,948,077	1,415,369
EST	7591	221,485	25,436	EST	8573	246,502	38,522
FIN	46,804	1,561,178	189,593	FIN	45,677	2,001,613	274,232
FRA	329,066	11,186,974	2,083,840	FRA	224,850	12,075,943	2262,380
GBR	437,583	10,155,918	1,745,866	GBR	657,235	9,209,026	1,792,147
GRC	60,184	1,379,768	193,492	GRC	62,894	1816,270	593,476
HUN	38,127	1,131,126	177,938	HUN	31,237	1,181,975	205,424
IRL	20,994	382,820	97,596	IRL	25,177	529,023	229,805
ITA	191,970	8,580,987	1,359,662	ITA	176,501	9,709,716	1709,808
JPN	630,458	27,643,161	5,485,319	JPN	520,568	27,999,345	5,595,722
KOR	165,084	8,845,539	1,802,244	KOR	241,891	14,325,538	2,118,001
MEX	553,758	7,127,460	828,910	MEX	799,443	8,274,053	1,246,229
NLD	503,707	5,317,980	891,586	NLD	441,941	5,561,005	1,057,367
POL	499,282	4,070,337	396,193	POL	306,760	4,344,064	719,110
PRT	29,805	1,204,640	156,021	PRT	35,294	1272,977	270,477
RUS	3,043,784	32,204,261	3,700,978	RUS	2,917,642	35,216,941	4,567,247
SVK	26,376	857,476	130,629	SVK	15,341	951,717	136,819
SVN	5628	204,074	39,192	SVN	6015	233,672	51,538
SWE	52,462	2,826,665	397,976	SWE	50,597	2,773,334	456,851
TUR	182,220	2,727,190	457,776	TUR	253,560	4,124,239	783,139
USA	3,513,741	91,794,967	25,368,198	USA	3,100,952	106,613,603	25,683,650

Table A.9
Level N-2: Human time allocated to economic sectors (HA_{PWi}) – Absolute values (millions of hours).

1995	Agr.	Ind.	Serv.	2007	Agr.	Ind.	Serv.
AUS	1054	3629	10,580	AUS	1070	4204	13,645
AUT	832	1702	3615	AUT	591	1655	4543
BEL	116	1470	3951	BEL	120	1344	4867
CAN	1426	5618	17,120	CAN	1333	6410	21,881
CZE	936	4012	5438	CZE	490	3841	5844
DEU	2388	18,844	36,447	DEU	1615	15,080	40,093
DNK	198	1001	2748	DNK	144	967	3379
ESP	2302	6598	14,614	ESP	1793	9877	22,087
EST	163	397	670	EST	74	449	748
FIN	419	965	2262	FIN	308	1129	2806
FRA	1816	9063	24,519	FRA	1476	8243	28,376
GBR	1072	10,349	33,573	GBR	866	8557	39,475
GRC	1721	1749	5299	GRC	1096	2075	6946
HUN	1228	2453	4399	HUN	651	2677	4949
IRL	367	723	1458	IRL	276	1148	2520
ITA	3175	11,903	25,522	ITA	2585	12,690	30,476
JPN	8453	42,008	77,762	JPN	5670	33,747	78,206
KOR	5825	17,629	27,709	KOR	3761	14,216	35,478
MEX	14,904	18,806	38,491	MEX	13,157	28,087	58,000
NLD	528	2403	7514	NLD	498	2312	9140
POL	9191	7825	11,289	POL	5225	8004	14,356
PRT	1054	3629	10,580	PRT	1146	2656	5787
RUS	832	1702	3615	RUS	34,624	35,539	80,231
SVK	116	1470	3951	SVK	167	1303	2414
SVN	1426	5618	17,120	SVN	188	606	946
SWE	936	4012	5438	SWE	233	1819	5268
TUR	2388	18,844	36,447	TUR	9543	10,350	19,730
USA	198	1001	2748	USA	6842	53,250	215,201

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