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Guiding European Policy toward a low-carbon economy. Modelling sustainable Energy system Development under Environmental And Socioeconomic constraints

Annex 9: Tasks 2.2.e.3. Current global and European energy per capita and link with social welfare. CO2 emissions

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Scope of document

This document provides analyses of the relation between energy use and social indicators. We review and analyze the relations between per capita energy use and Gross Domestic Product, and the relations between per capita energy use and the Human Development Index. We also take into account the energy footprint, to determine which relationship is stronger and should be taken into account in the model. We further extend the analysis to take into account inequality.

Given that the HDI is a composite indicator, we also extend the analysis to separate social dimensions that could be added to the model structure. Specifically, we analyze the relation between education, working hours, and energy intensity, as potentially exogenous parameters of policy making to be considered in the MEDEAS model structure.

List of abbreviations and acronyms

GDP – Gross Domestic Product

GHG – Greenhouse gases

HDI – Human Development Index

IEA – International Energy Agency

NACE – The Statistical classification of economic activities in the European Community

RES – Renewable energy sources

WIOD – World Input Output Database

Executive summary

Energy consumption levels may be strongly connected with social development. The relation between energy consumption and social indicators has been analyzed extensively. Many studies demonstrate strong correlations between energy consumption and living standards at lower levels of “development”, but this relation weakens with increasing stages of “development” (see, e.g. Steinberger and Roberts, 2010). Arto and colleagues (Arto et al., 2016) show that the relation is considerably stronger when the HDI is related to the energy footprint. This has important consequences for model development: If the HDI is taken as a key indicator of model outcomes, then the link may be preferably made with the energy footprint. Alternatively, combinations of GDP and energy consumption could be tested as explanatory variables for the HDI composite.

Also the link of energy consumption to the education level, unemployment, working hours and labor sharing may have to be considered in the model framework. The first dimension, namely education and training, may be a key parameter for some policy makers and stakeholders more generally. The effects of the scenarios and pathways of low-carbon energy transition may also result in different levels of labor demand and resulting unemployment. In addition, some stakeholders may consider reduced work time and would be interested in its effects on the future economy. Therefore, we analyze relations between working hours, Gross Domestic Product, and the energy intensity of an economy.

We use the WIOD database for sector-specific gross output, value added, energy use, skill of labor, and hours worked. Therefore, we draw from the main WIOT structure (Dietzenbacher et al., 2013) and from the environmental and socio-economic satellite accounts. The environmental accounts include data on energy flows in each of the NACE entities. WIOD uses the international energy balances provided by the IEA based on a joint annual survey by IEA/OECD/ESTAT/UNECE with harmonised methodologies and definitions, and derives sector-level energy accounts (Genty et al., 2012). Data on employment by skill levels, wages, and total hours worked have been collected from different sources, in most cases from the labor force survey (LFS). For most OECD countries, labor data from the EU KLEMS database is used (Erumban et al., 2012).

Our results support some existing MEDEAS model relations, but provide suggestions for changes and additions in others. While the relation between income and energy consumption has been extensively studied, the country level variables and properties have received less attention. This could have important consequences for model development, also when focusing on a global scale.

The influence of climate change on heating and cooling, e.g., could influence this relation. A random effects panel regression could reveal such country-level differences.

We find that education has an effect on energy intensity and could therefore be an important policy parameter. Therefore, energy intensity could be endogenized in the model. We show that energy intensity critically depends on human capital, specifically, on the share of high-skilled persons working in each sector. At the same time, education is also a critical exogenous variable that might be considered by some policy makers and MEDEAS model stakeholders more generally.

The Human Development Index, as a composite index, is obviously most strongly related to its component elementary indices, variables, and proxies. Inequality and education are two key components of the HDI. Inequality, as studied in task 2.2.e.1., is both an important result and a potential driver of aggregate income (GDP) and consequently also energy consumption. Similarly, also education has an influence on other model parameters. Therefore, a decomposition or step-wise partial aggregation should be considered in model development to take into account the endogeneity of some of the variables included in the HDI.

As shown by some indicative analyses, a low-carbon energy transition may effect labor demand and therefore result in different levels of unemployment,. Finally, we find relations between working hours and GDP that could be considered to take into account policy measures related to labor sharing, which is considered crucial by some authors concerning a general sustainability transition.

The number of hours worked per person could also be a crucial variable to be considered by society and stakeholders using the model. The hours worked is related to the value added per person working in each sector, and the energy intensity of each sector. There appears to be an optimum of hours worked for value added, which is, however, closely related to a peak in energy intensity. An optimization procedure could find the optimal level between both relationships. Above a certain threshold, there is a clearly negative relation to value added. There may be causal relationships with fixed costs of employed persons, but these need to be further investigated if the relationship is considered to be included in the model.

Introduction

The per capita consumption of energy is an important explanatory variable in human development. The relation between energy consumption and social indicators has been analyzed extensively (see, e.g. Steinberger and Roberts, 2010). Many studies demonstrate strong correlations between energy consumption and living standards at lower levels of “development”, but this relation weakens with increasing stages of “development”. Most frequently, the relation of the Human Development Index (HDI) with primary energy demand has been studied. Recently, also the indirect energy footprint has been analyzed. Arto and colleagues (Arto et al., 2016) show that the relation is considerably stronger when the HDI is related to the energy footprint. This has important consequences for model development: If the HDI is taken as a key indicator of model outcomes, then the link is best made with the energy footprint.

Inequality and education are two key components of the HDI. Inequality, as studied in task 2.2.e.1., is both an important result and a potential driver of aggregate income (GDP) and consequently also energy consumption. Similarly, also education has an influence on other model parameters. The following relations make this clear:

First, higher education may lead to a reduced energy intensity in production, as shown in the report. Second, equality is related to higher GDP levels, but also to higher energy demand. A low-carbon energy transition may also effect direct and indirect labor demand and therefore result in different levels of unemployment, as shown by some indicative analyses.

Therefore, also the education level, unemployment, and working hours and labor sharing may have to be considered in the model framework. The first dimension, namely education and training, may be a key parameter for some policy makers and stakeholders more generally. We show that labor skill levels have an effect on energy intensity and could therefore be an important policy parameter.

Second, the effects of the scenarios and pathways of low-carbon energy transition may not only result in different levels of labor demand and resulting unemployment, but, in addition, some stakeholders may consider reduced work time and would be interested in its effects on the future economy. Therefore, we analyze relations between working hours, Gross Domestic Product, and the energy intensity of an economy. Data for the necessary analyses is publicly available from different sources and does not pose any serious constraints, as the subsequent section shows.

Methodology

We use the WIOD database for sector-specific gross output, value added, energy use, skill of labor, and hours worked. Therefore, we do not only draw from the main WIOT structure (Dietzenbacher et al., 2013; Timmer et al., 2015), but also from the environmental and socio-economic satellite accounts. Table 1 provides an overview.

Table 1: Data sources

	Type	Source
WIOD	Input Output tables	Dietzenbacher et al. 2013
EU KLEMS	Socio-Economic Accounts	Erumban et al. 2012
IEA et al.	Energy use	Genty et al. 2012
World Bank database	Population, demographics, Gini coefficient, etc.	

The environmental accounts include data on energy flows in each of the NACE entities. WIOD uses the international energy balances provided by the IEA based on a joint annual survey by IEA/OECD/ESTAT/UNECE with harmonised methodologies and definitions, and derives sector-level energy accounts. The correspondence key is easily established for some of the NACE entities, but in some cases, the energy balance needs to be related to more than one industry. This is the case for “road transport”, which is distributed to all industries and households, and “commerce and public services” (Genty et al., 2012).

Another problem occurs due to the differences between national accounting frameworks and national inventory balances due to the residence principle used in the former, and the territorial principle used in the latter. This is especially critical in the case of all transport sectors, for which a bridging framework is necessary (Genty et al., 2012, p. 8). Any analyses related to territories and transport should therefore be done with caution, considering the implications of the data bridge.

Data on employment by skill levels, wages, and total hours worked have been collected from different sources, in most cases from the labor force survey (LFS). For most OECD countries, labor data from the EU KLEMS database is used. One caveat emerges concerning the underrepresentation of self-employed labor, which leads to imputation difficulties especially for less advanced economies and the agricultural, trade, business, and personal services sectors (Erumban et al., 2012).

For skill levels, the 1997 International Standard Classification of Education (ISCED) is used to categorize low, medium, and high skill labor. Low skills include basic education, including lower secondary, medium skills include secondary and post-secondary, but non-tertiary education, and high skills include first and second stages of tertiary education (Erumban et al., 2012, p. 4). Caveats of imputations for wage data are not relevant here, because no analyses are based on this data.



Results

Per capita energy use

Per capita energy use is a key variable in the MEDEAS model. A decomposition to end uses shows that residential energy consumption remains a key contributor, but the share of transport has increased considerably (Chow et al., 2003). The following figure demonstrates the split:

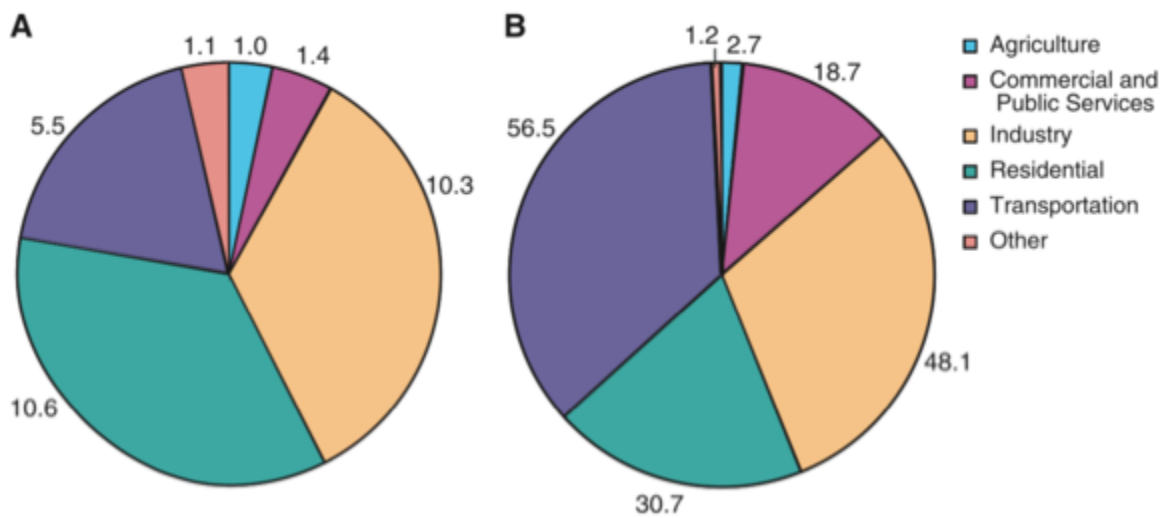


Figure 1: Per capita energy consumption in the developing (A) and developed world (B)

Source: (Chow et al., 2003)

The WIOD input-output framework allows us to clearly separate the final energy use by households from the intermediate uses. We can also separate for each energy type. The following figures compare per capita electricity consumption versus total final household energy consumption:

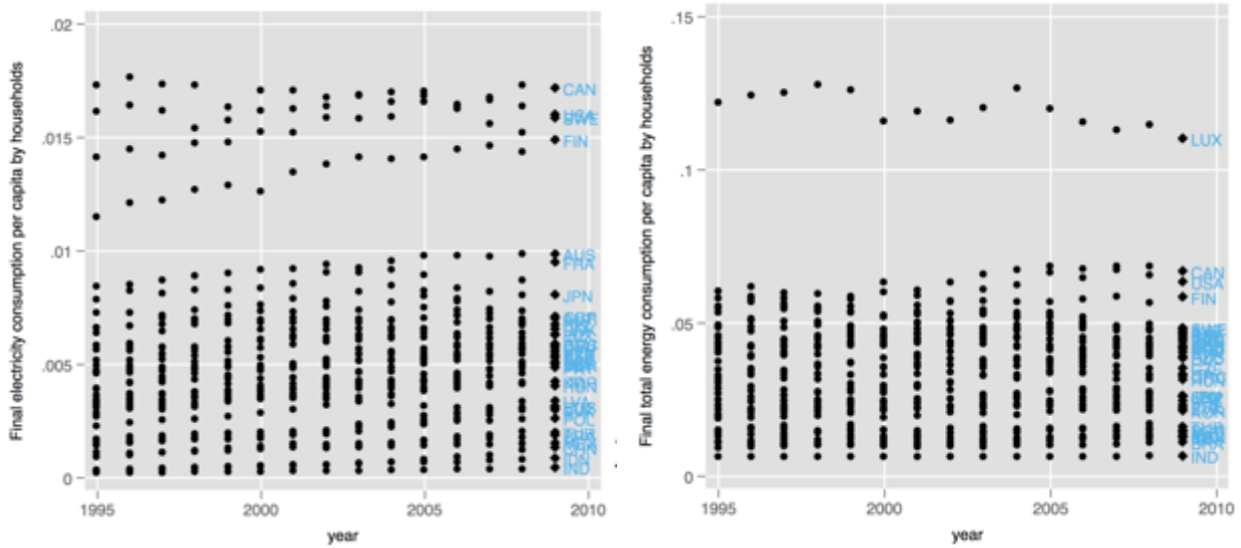


Figure 2: Final electricity (left) and total energy use (right) of households per capita

Source: own calculations based on WIOD, IEA and World Bank data

Note that the y axis is displayed in Terajoule. To give an idea of the magnitudes, 1.000 kWh equals 0.0036 Terajoule (TJ). The total final per capita energy consumption by households is one order of magnitude higher, including household consumption for heating and mobility. The outliers also differ concerning both: While Canada, the US, and Finland, show a relatively high use of electricity, which is plausible, Luxembourg is an outlier with regards to total household energy use per capita, very likely due to the accounting limitations that have been mentioned in the methods section, namely the difference between the residence and the territorial principle.

In comparison to the final energy use, the domestic intermediate energy use, excluding indirect energy use from other countries via imports, is considerably higher. As can be seen in the following figure, also the heterogeneity among countries is much larger than in the case of household energy consumption.

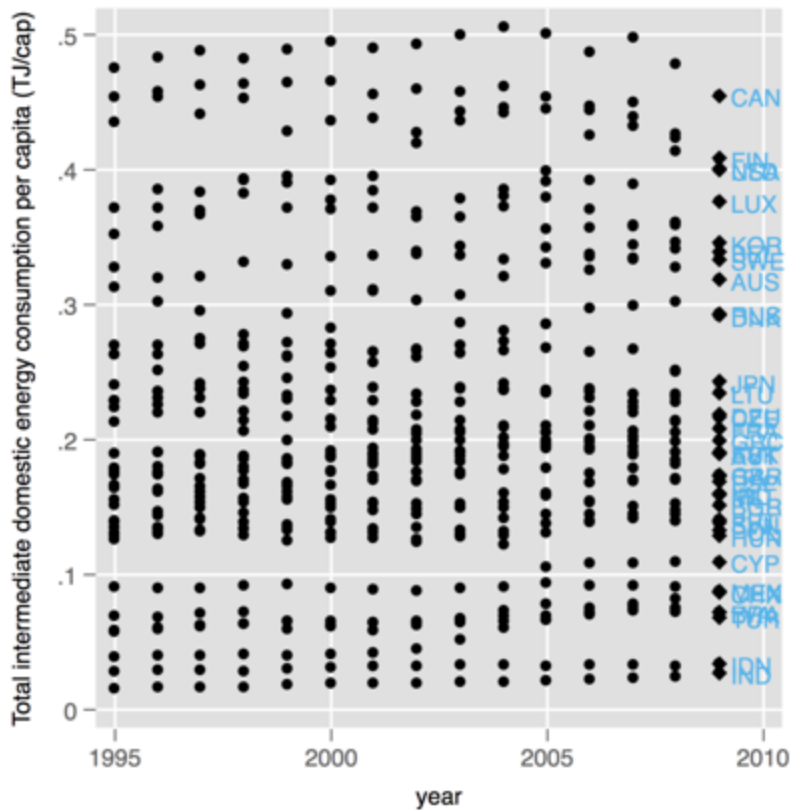


Figure 3: Domestic intermediate energy use per capita

Source: own calculations based on WIOD, IEA and World Bank data

Per capita energy use and GDP

Important relations for the MEDEAS model result from the effect of income increase (GDP per capita) on direct and indirect energy use. The following figure depicts the relation between GDP per capita (in constant 2010 USD) and final household energy consumption:

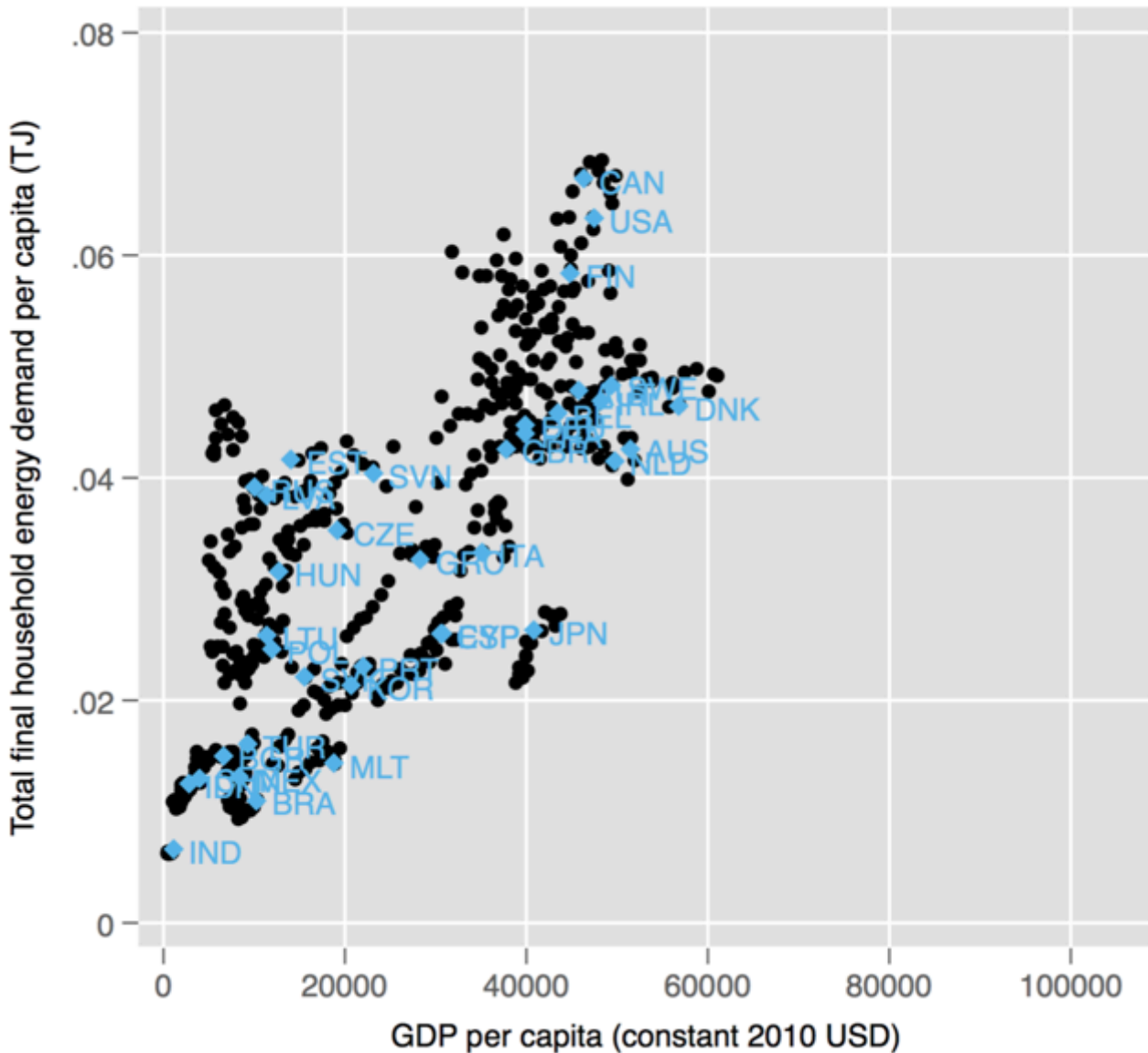


Figure 4: Relation between final per capita energy demand of households and GDP per capita

Source: own calculations based on WIOD, IEA and World Bank data

While the relation between income and energy consumption has been extensively studied (Lee and Chang, 2007), the country level variables and properties have received less attention. This could have important consequences for model development, also when focusing on a global scale. The influence of climate change on heating and cooling, e.g., could influence this relation. As can be seen in the figure, countries with a similar level of GDP differ significantly in household energy demand, partially due to the different heating requirements due to the climatic conditions. A random effects panel regression could reveal such country-level differences.



HDI: Energy consumption or footprint as explanatory variable?

Above a certain level of GDP, the HDI decouples from income. This has been shown by multiple studies (see, e.g. Martinez and Ebenhack, 2008). Therefore, it is important to consider other relations that may better explain the HDI index. Among these, energy consumption may be an important relation.

In fact, this relation has been studied by several authors (see, e.g. Steinberger and Roberts, 2010). However, the energy footprint explains the HDI much better than total primary energy demand (Arto et al., 2016), as the following figure demonstrates :

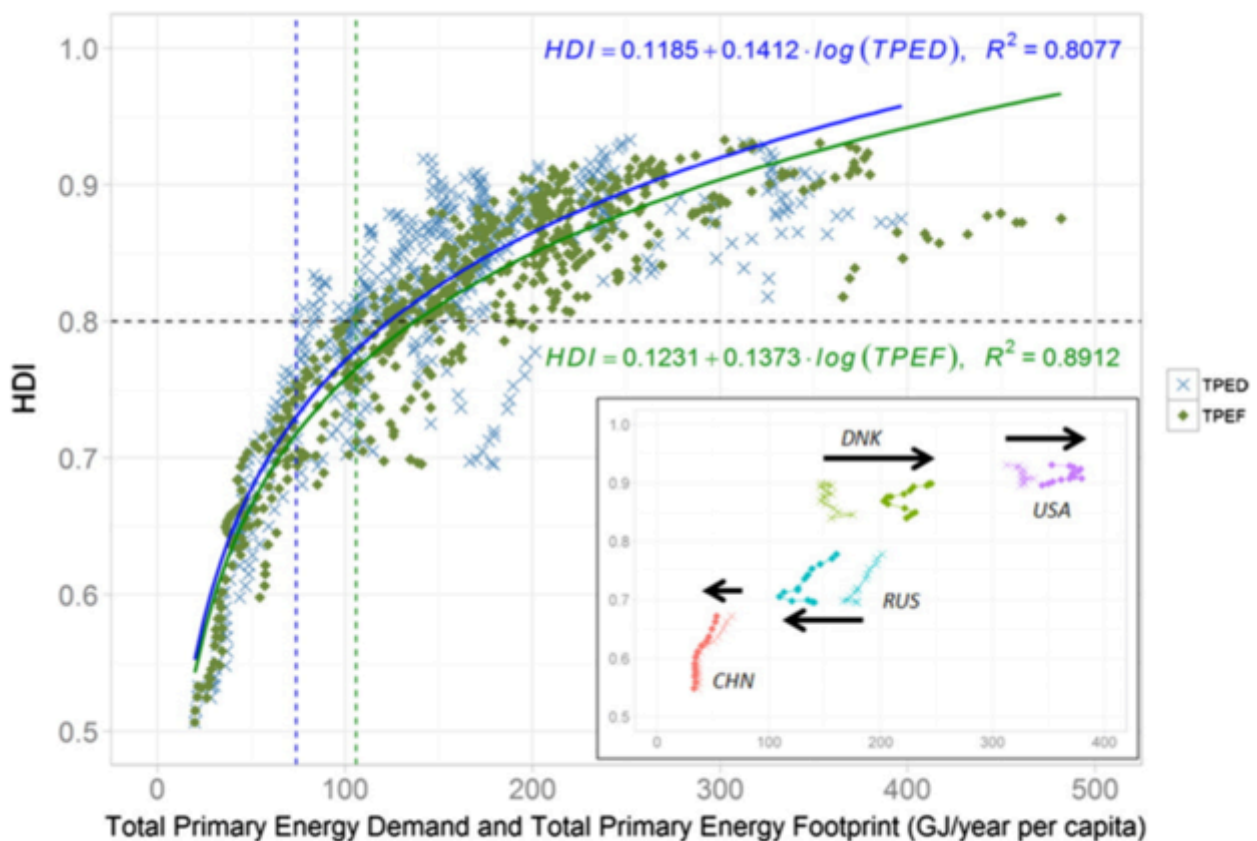


Figure 5: Relations between HDI and direct and indirect energy demand

Source : (Arto et al., 2016)

Naturally, the composite index is presumably most strongly related to its component elementary indices and proxies. Inequality and education are two key components of the HDI. Inequality, as studied in task 2.2.e.1., is both an important result and a potential driver of aggregate income (GDP) and consequently also energy consumption. Similarly, also education has an influence on other model parameters. The following points provide reasons to consider a disaggregation of the HDI composite:

Equality is related to higher GDP levels, but also to higher energy demand. A careful specification could therefore increase the model precision considerably. This will be shown in the subsequent section.

As shown in the section following inequality, energy consumption and education are related in multiple ways. Higher education may lead to a reduced energy intensity in production.

Finally, we find relations between working hours and GDP that could be considered to take into account policy measures related to labor sharing, which is considered crucial by some authors concerning a general sustainability transition. In addition, a low-carbon energy transition may also effect labor demand itself and therefore result in different levels of unemployment, as shown by some indicative analyses.

Inequality and energy consumption

Inequality could potentially effect energy consumption in multiple ways. An indirect effect could result from lower levels of GDP associated with higher inequality, which in turn reduces demand for energy.

The following figure provides a first indication of the relation that exhibits similarities with the relation between inequality and GDP. While energy demand is increasing with lower inequality, there are countries with similar levels of equality that show considerable differences with regards to energy consumption, and this difference is not fully explained by the respective GDP level.

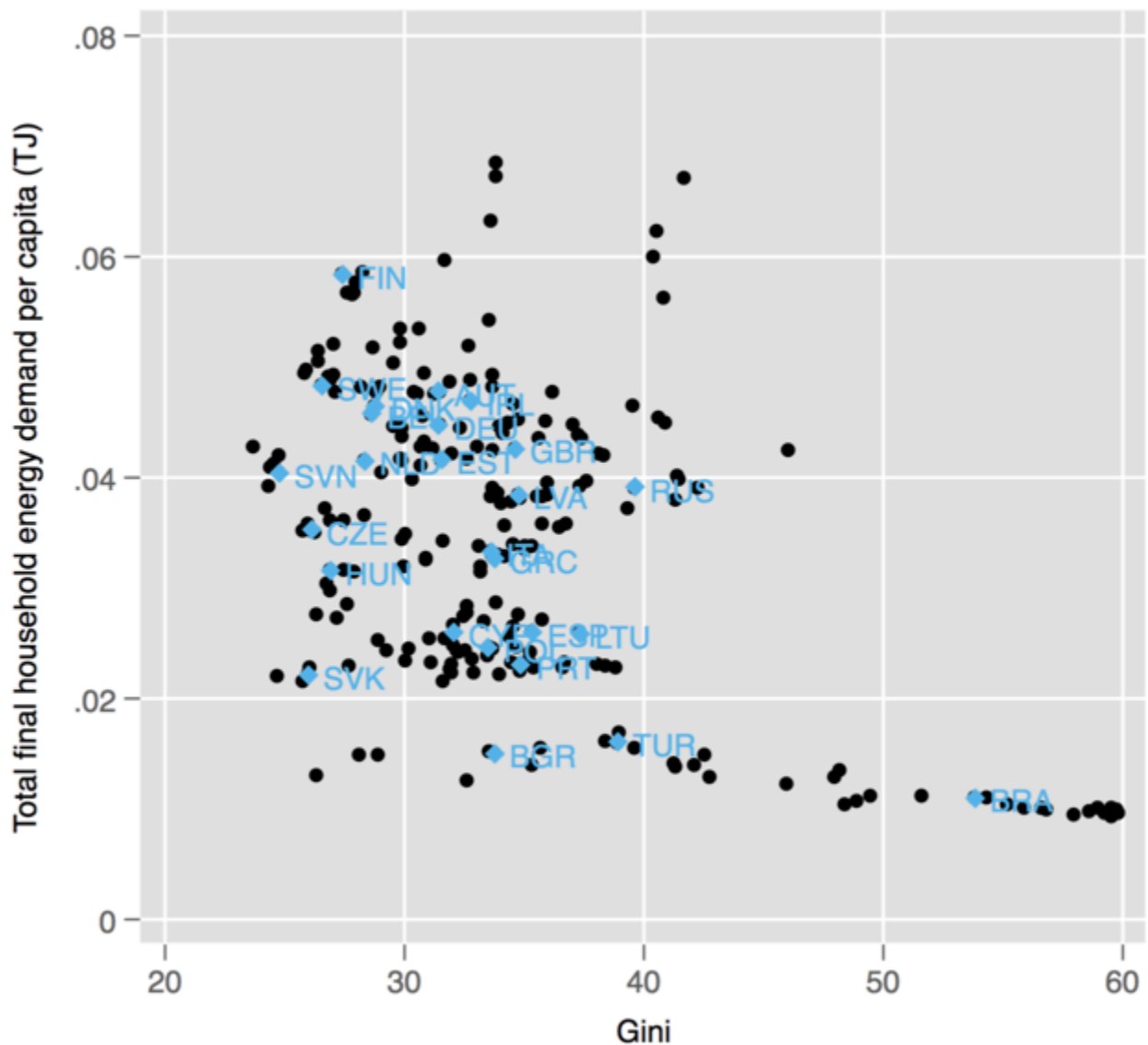


Figure 6: Inequality and energy consumption

Source: own calculation based on WIOD

A further link that could become relevant is the effect of inequality on population development. There is a strong, statistically significant, and consistent correlation between income inequality, based on data from 1970 and 1995, and life expectancy (Babones, 2008). A causal relation is difficult to establish statistically because of the slow change in income inequality during these years. Nevertheless, more recent studies could provide further indications to establish a corroborated relation in the MEDEAS model.



Energy intensity and human capital: The role of education

A key parameter in the MEDEAS model is the energy intensity of production. As MEDEAS builds fundamentally on the WIOD input-output structure, the energy intensity of the economy is divided into the sectors provided in WIOD (Dietzenbacher et al., 2013; Timmer et al., 2015). This sector level disaggregation is important, as can be seen from an analysis of energy intensity in each sector provided in the WIOD database.

Voigt et al. (2014) show that heterogeneity is high within each sector when compared with the heterogeneity across countries, although there is some convergence (Mulder and De Groot, 2012). This heterogeneity naturally leads to the question, which drivers could explain this difference. This is a crucial question for model building purposes, as an explanatory driver could result in making the variable endogenous and providing a potential policy variable. The following figures show the heterogeneity between sectors and between countries:

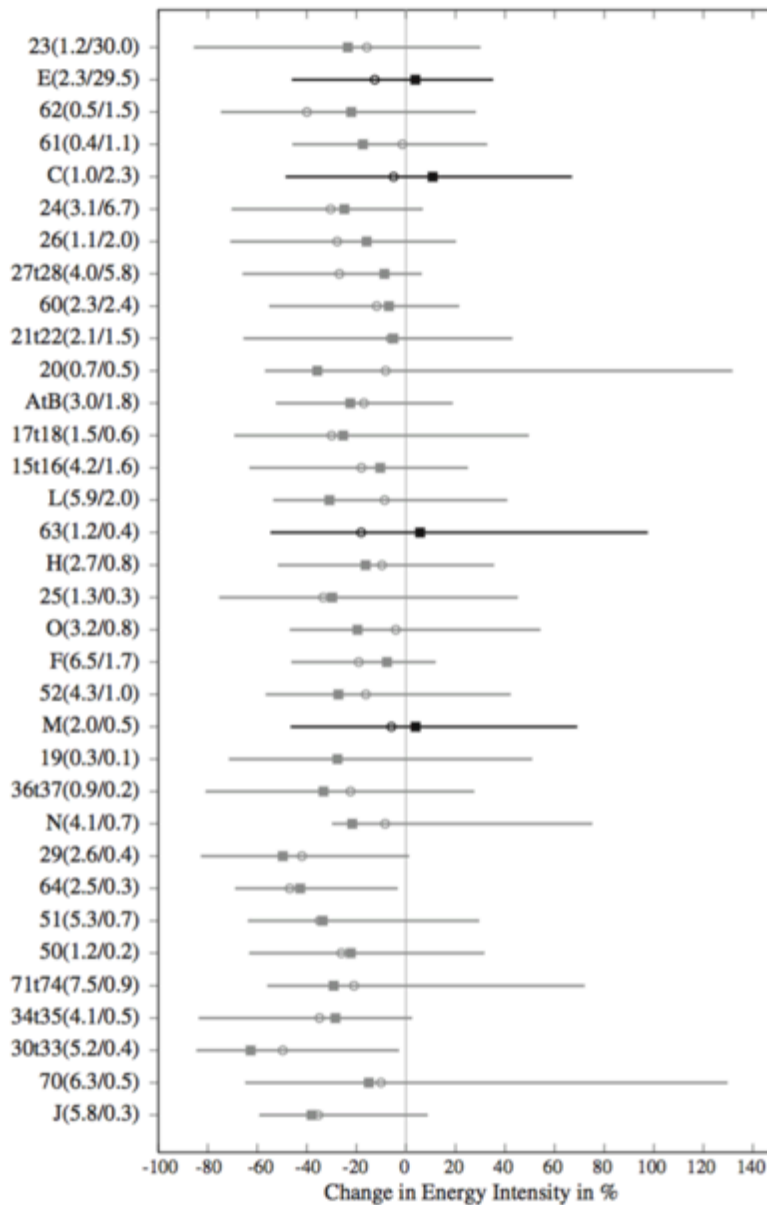


Figure 7: Energy intensity change across sectors

Source : (Voigt et al., 2014)

Empty circles show the median change in energy intensity across countries. Filled squares depict the output-weighted mean changes. If we take into account the size of each economy, we can therefore see that energy intensity has actually increased in four sectors, namely, electricity, gas, and water supply (Sector E), mining and quarrying (Sector C), supporting and auxiliary transport services (Sector 63), and education (Sector M). But the heterogeneity across countries is relatively



high. It would therefore be important to know, where this heterogeneity comes from and which variables could explain the difference. The next figure shows the energy intensity across countries:

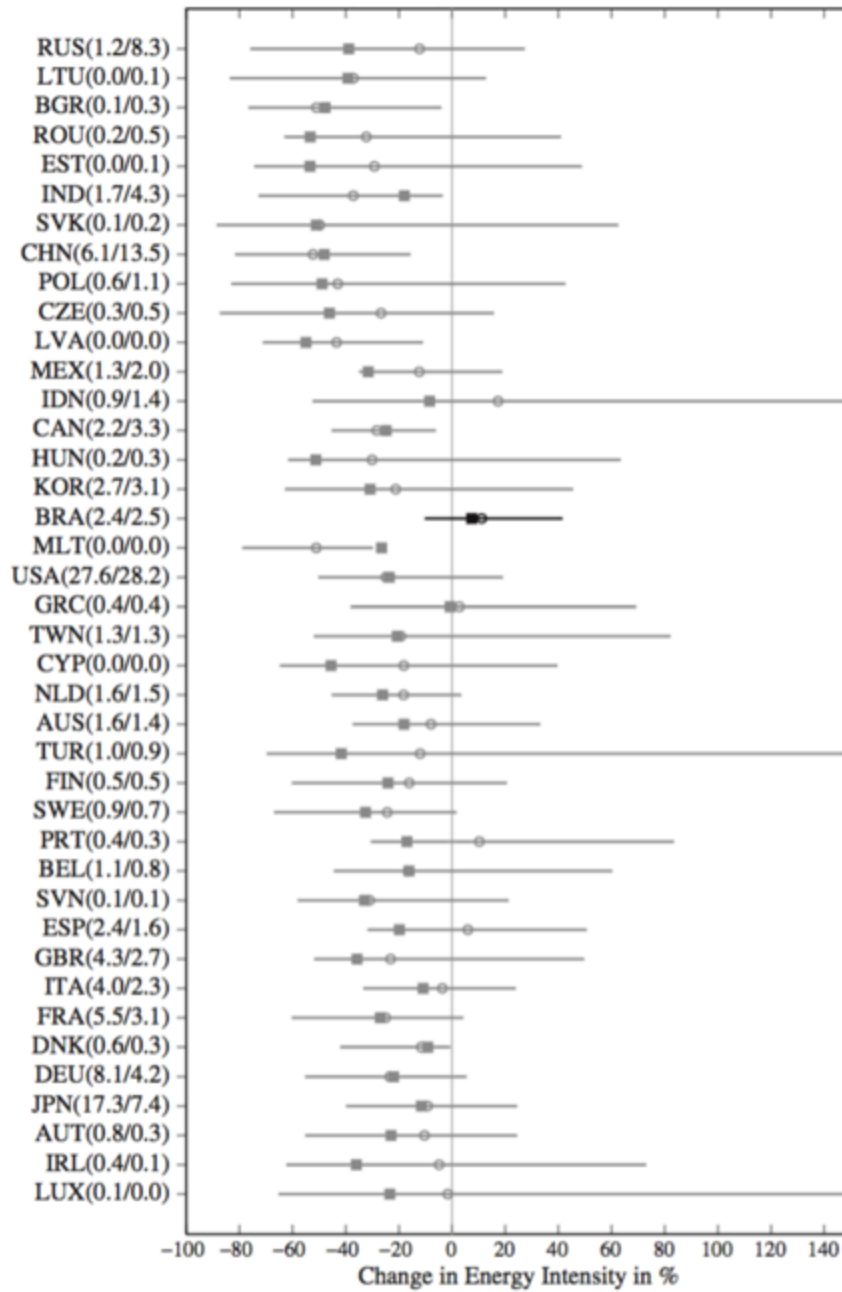


Figure 8: Energy intensity across countries

Source : (Voigt et al., 2014)

Except for Brazil, all countries have reduced their output-weighted mean energy intensity, but the heterogeneity across sectors in each country is also relatively high, as could be expected from the preceding figure that shows the difference across sectors.

It is intuitively plausible that education and technical skills may influence the adoption, use, and maintenance of energy-efficient technology.

Given that education may also be a very important policy measure that could be considered by policy makers and several other stakeholders of the MEDEAS model, we have therefore decided to specify and test several relations.

The relation between log-normal energy intensity and the share of high-skilled persons working in each sector, as depicted in the figure below, clearly reveals a systematic relationship. The higher the skill of labor, the lower the energy intensity (log scale):

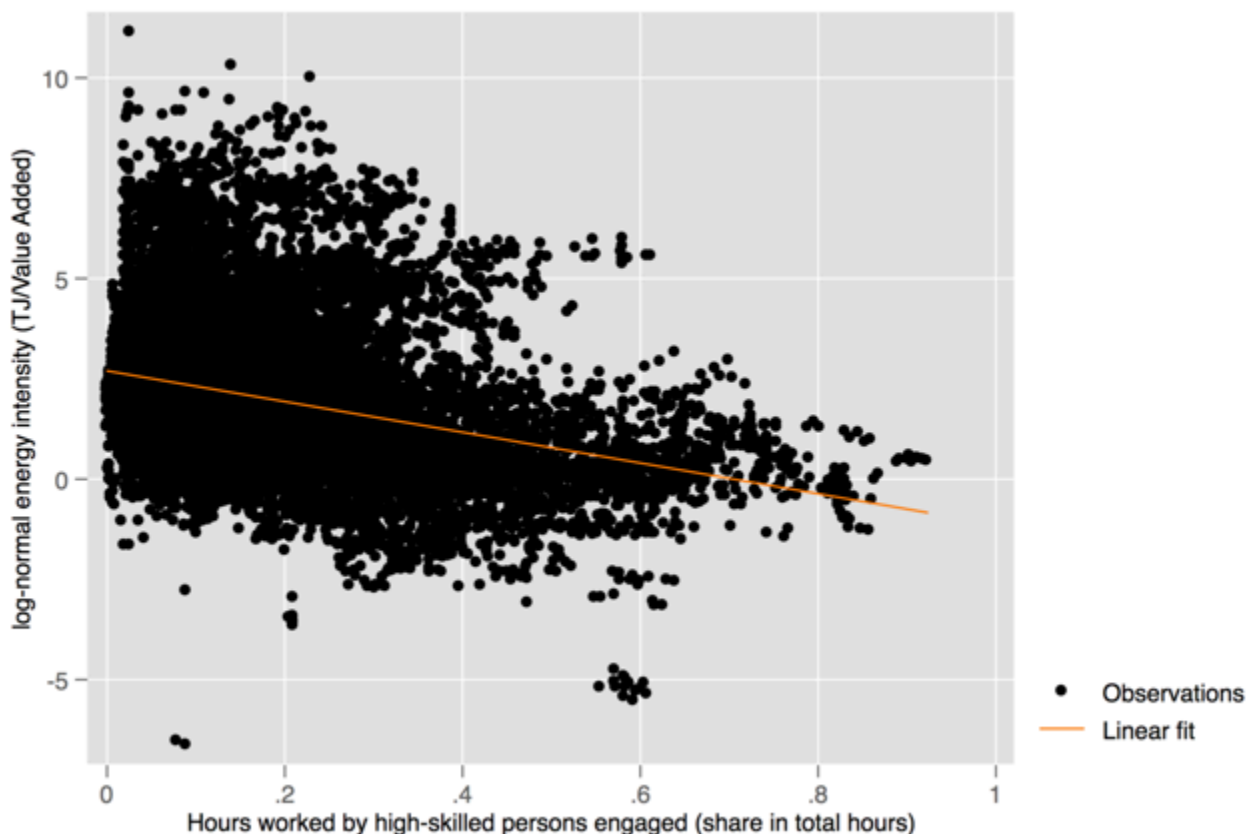


Figure 9: Energy intensity and share of high-skilled persons engaged

Source : own calculations based on WIOD and IEA Energy Use accounts

Note that this relation is reversed if the share of medium-skilled persons increases:

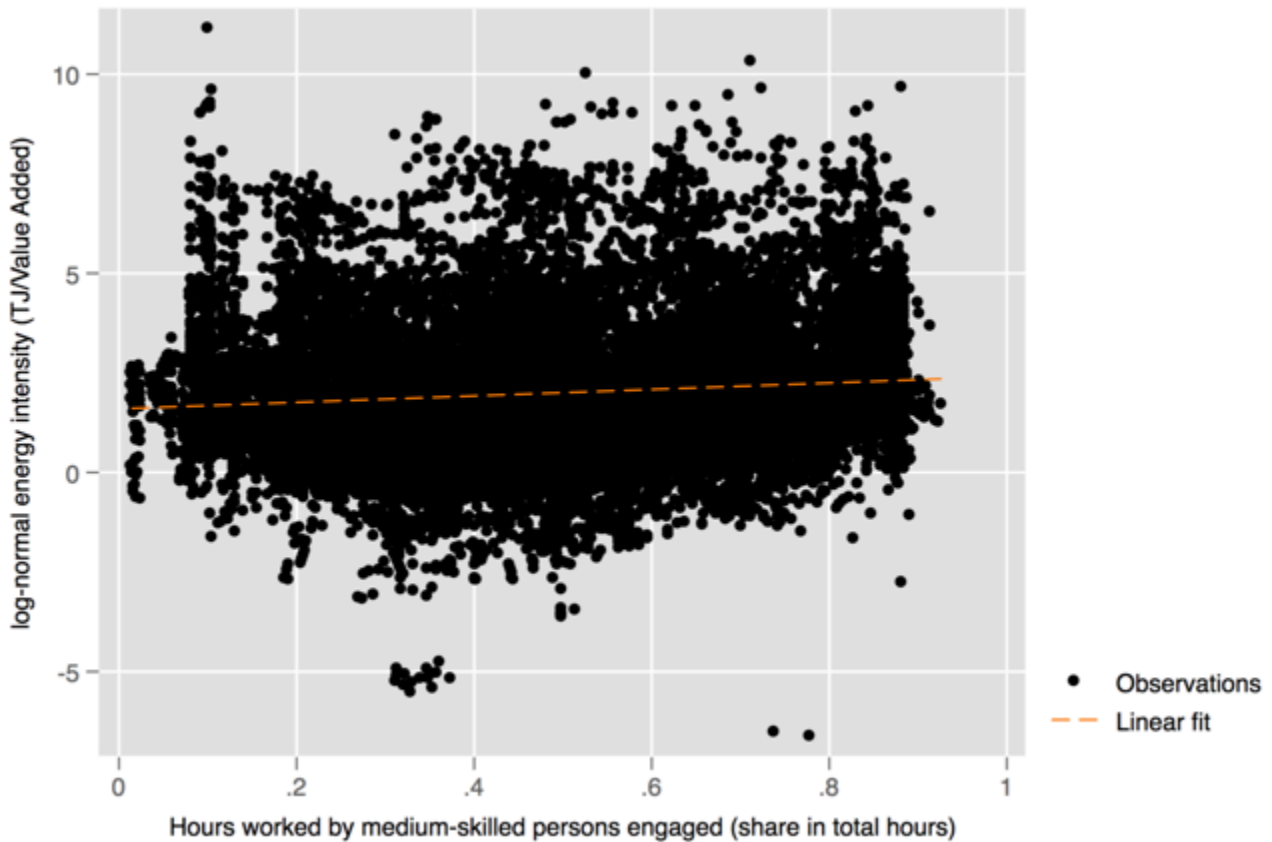


Figure 10: Energy intensity and share of medium-skilled persons engaged

Source : own calculations based on WIOD and IEA Energy Use accounts

Apparently, the skill level of labor can explain a significant portion of the energy intensity. But there are huge differences between sectors and some outliers. The relation is far less apparent if we look, for example, at the sector “Agriculture, Hunting, Forestry, and Fishing” (Sector 1) in the WIOD database, in comparison to the sector “Mining and Quarrying” (Sector 2):

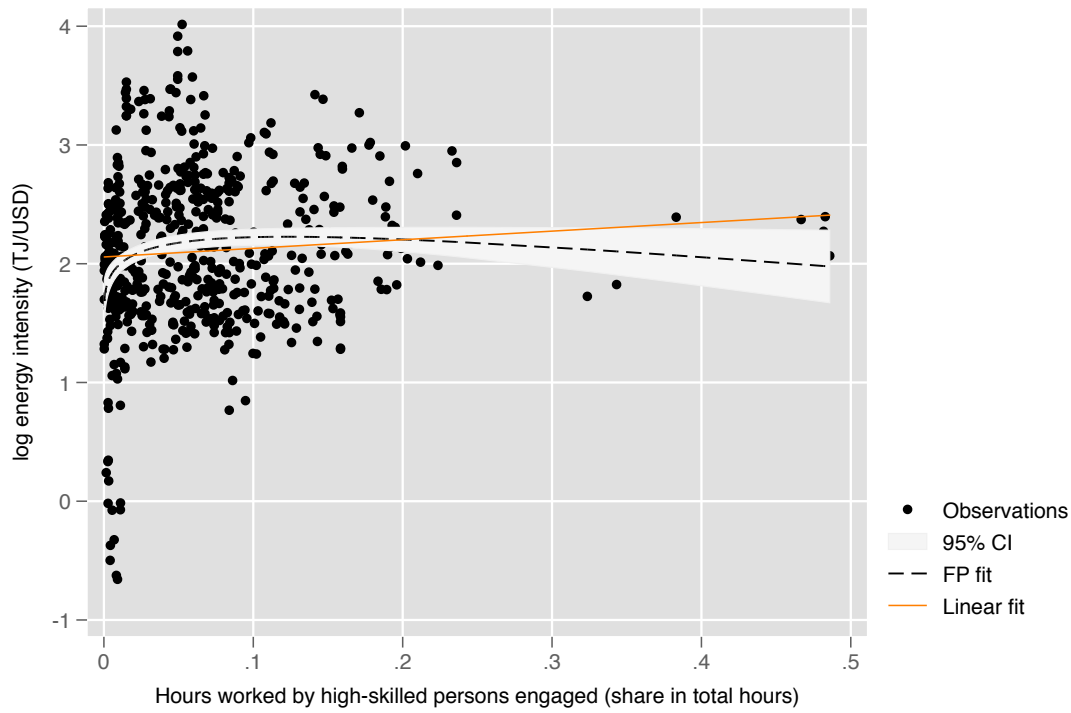


Figure 11: Energy intensity and high-skill share in agriculture

Source : own calculations based on WIOD and IEA Energy Use accounts

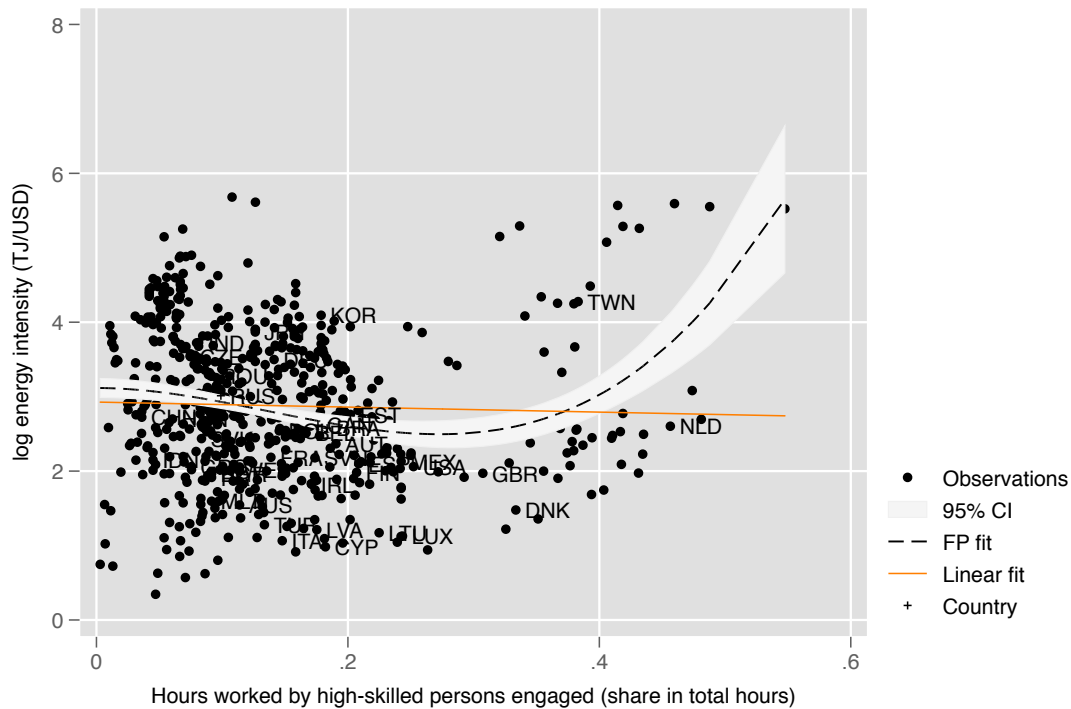


Figure 12: Energy intensity and high-skill share in mining and quarrying

Source : own calculations based on WIOD and IEA Energy Use accounts

The relation is, in some cases, also strongly influenced by some outliers, such as Taiwan in the case of sector 2. But a U-shaped relation seems to hold for several key sectors, including “Electricity, Gas, and Water Supply” (sector 17):

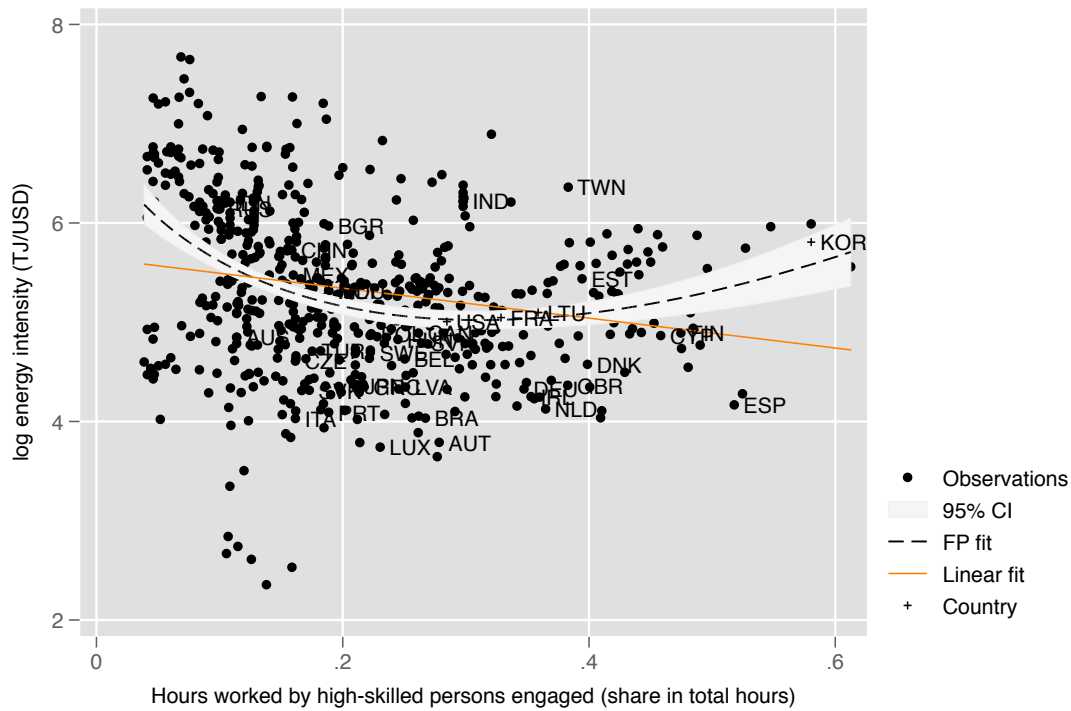


Figure 13: Energy intensity and high-skill share in electricity, gas, and water supply

Source : own calculations based on WIOD and IEA Energy Use accounts



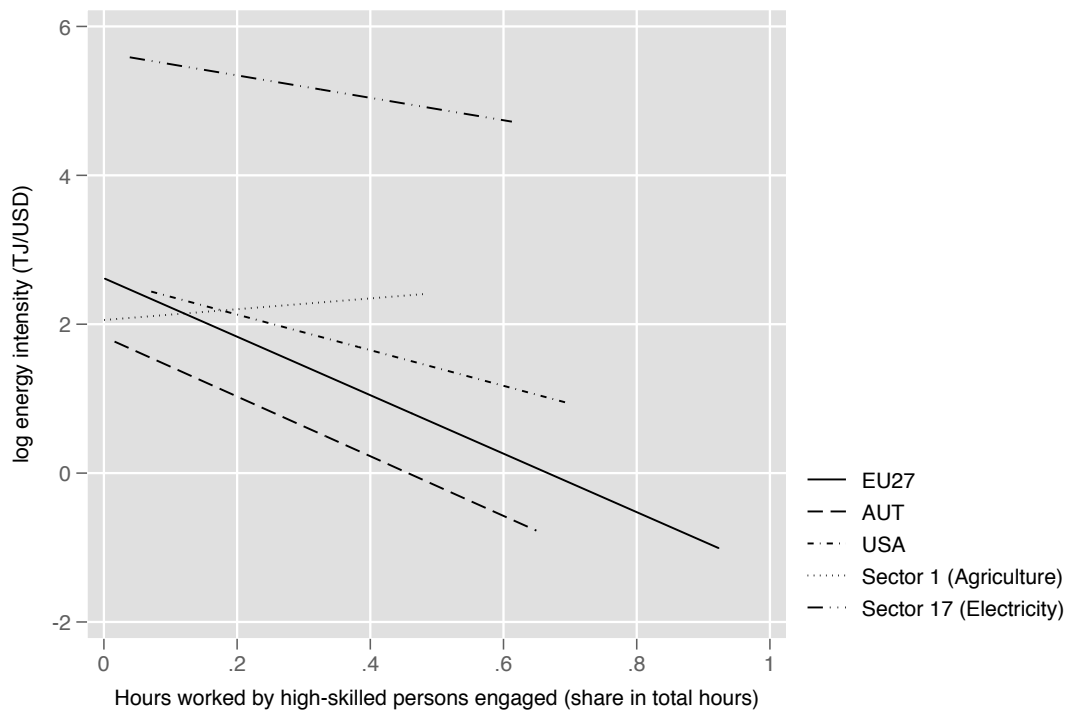


Figure 14: Energy intensity and high-skill share in between countries and sectors

Source : own calculations based on WIOD and IEA Energy Use accounts

The last figure depicts the linear fit across all sectors of the EU27, the US, and Austria, and sector 1 and 17 across all countries. As visible, the differences are far less pronounced between countries, than between sectors.

If a decision is taken to make the development of energy intensity endogenous in MEDEAS, then further analyses are required to specify the relation that best represents endogenous change, while taking into account the implications of non-linear relations in the System Dynamics framework.

Social welfare: value added and labor sharing

Another policy variable that might be relevant for several stakeholders concerning the relation to social welfare is labor sharing and reduced working hours. This policy has been considered in the past and also translated into practice, e.g. in France. The reduction of working hours and sharing of labor is currently discussed in the context of economic growth and sustainability (Zwickl et al., 2016) and has been a focus of the FP7 project “WWWforEurope”.

A key question in the context of MEDEAS is whether a reduction of working hours per person working in each sector could indirectly reduce energy intensity besides reducing unemployment. Secondly, due to fixed labor costs per person, the reduction of working hours and labor sharing could lead to an overproprtional reduction of value added.

Finally, a key question concerns the causality. Does a higher value added per hour lead to a reduction in work hours, or do increaseing hours of work influence the value added? There are clearly increasing and decreasing returns to the number of working hours, as a first analysis reveals. Here we provide a first approximation to the relation between hours worked per person and value added per person.

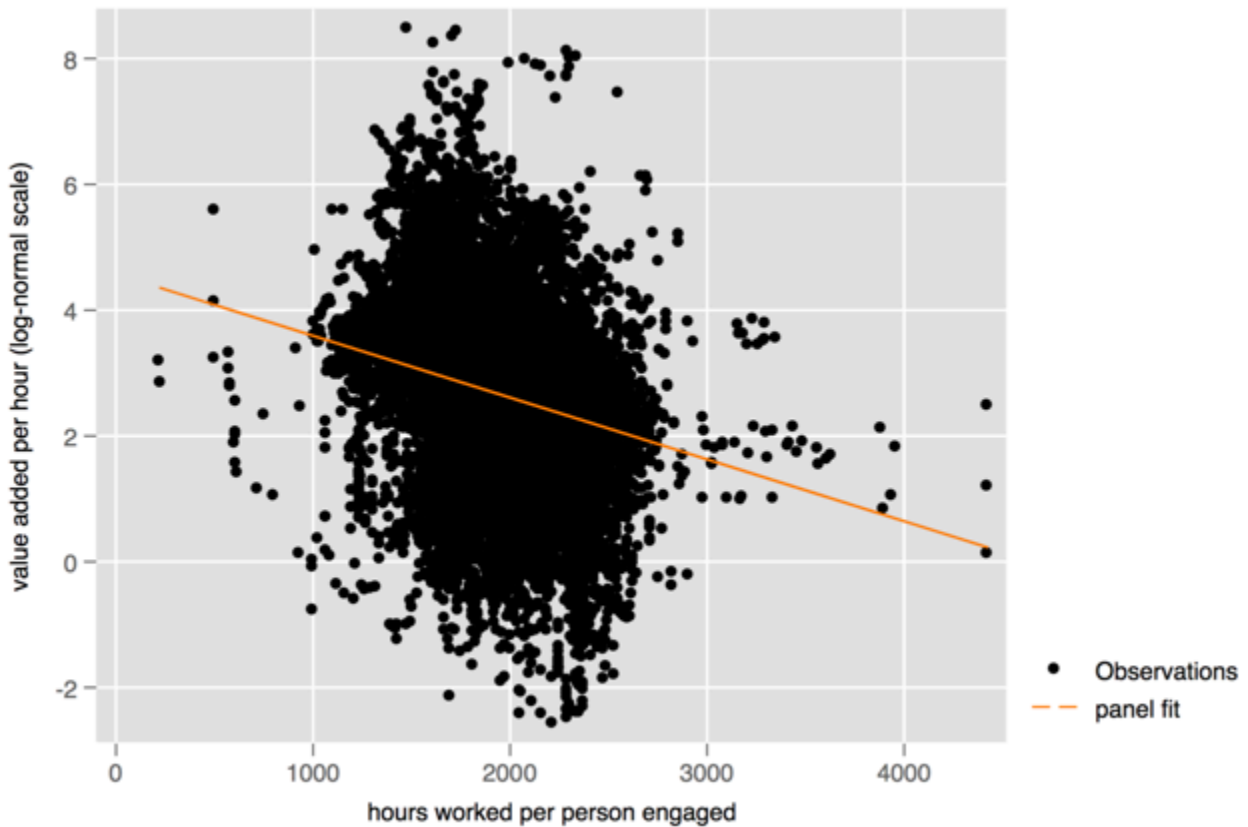


Figure 15: Value added per hour and hours worked per person

Source: own calculation based on WIOD and

A linear panel fit indicates a decline in value added for each country with increasing working hours. But this first linear approximation has a poor fit, with an R2 of 5.1% for changes within countries, and an R2 of 14% for differences between countries. The relation is nonlinear, and also differs considerably across sectors. The following figure depicts the relation for the “Inland Transport” sector (Sector 23).



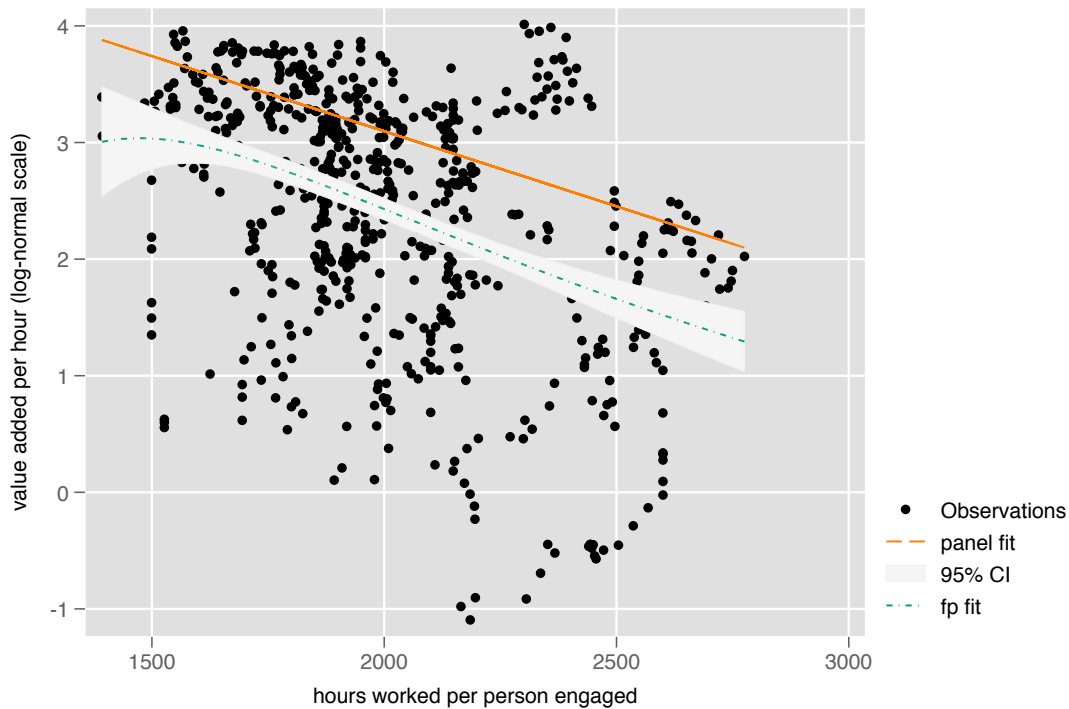


Figure 16: Value added per hour and hours worked in the inland transport sector

The relation is also statistically significant, the R2 slightly higher (6.7% within), and the decline is one order of magnitude higher than across all sectors.

If labor sharing and related policy variables are considered important and these relationships are to be implemented, then also the indirect relation with energy intensity, and potential repercussions and feedback loops have to be analyzed in more detail.

Conclusions

Our results support some existing MEDEAS model relations, but provide suggestions for changes and additions in others. The relation between energy demand and GDP is well studied and proven. While the relation between income and energy consumption has been extensively studied, the country level variables and properties have received less attention. This could have important consequences for model development, also when focusing on a global scale. The influence of climate change on heating and cooling, e.g., could influence this relation. A random effects panel regression could reveal such country-level differences.

The correlation between HDI and energy consumption has been studied extensively by several authors and the closest relation is found with the energy footprint, which includes indirect energy consumption. A link to the HDI could therefore be established, because input output relations are already explicitly modeled in MEDEAS.

A replacement of the HDI by its constituent variables should be considered, because some of the constituent variables are endogenous. Inequality and education are two key components of the HDI. Inequality is both an important result and a potential driver of aggregate income (GDP) and consequently also energy consumption. Similarly, also education has an influence on other model parameters. Therefore, a decomposition or step-wise partial aggregation should be considered in model development to take into account the endogeneity of some of the variables included in the HDI, because, first, higher education may lead to a reduced energy intensity in production, as shown in the report, and, second, equality is related to higher GDP levels, but also to higher energy demand. A careful specification could therefore increase the model precision considerably.

We find that education has an effect on energy intensity and could therefore be an important policy parameter. Therefore, energy intensity could be endogenized in the model. We show that energy intensity critically depends on human capital, specifically, on the share of high-skilled persons working in each sector. At the same time, education is also a critical exogenous variable that might be considered by some policy makers and MEDEAS model stakeholders more generally.

Finally, a low-carbon energy transition may effect labor demand and therefore result in different levels of unemployment, as shown by some indicative analyses. We find relations between working hours and GDP that could be considered to take into account policy measures related to labor sharing. The number of hours worked per person could also be a crucial variable to be considered by society and stakeholders using the model. The hours worked is related to the value



added per person working in each sector, and the energy intensity of each sector. There appears to be an optimum of hours worked for value added, which is, however, closely related to a peak in energy intensity. An optimization procedure could find the optimal level between both relationships. Above a certain threshold, there is a clearly negative relation to value added. There may be causal relationships with fixed costs of employed persons, but these need to be further investigated if the relationship is considered to be included in the model.



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