This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

EU Framework Program for Research and Innovation actions (H2020 LCE-21-2015)

Project Nr: 691287

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

D4.3 Annexes 1-4: Exogenous Energy Intensity Targets, Fuel Replacement conditions, imports and inclusion of public transportation policies in the MEDEAS country-level models

Version 3.0.0

Due date of deliverable: 30/06/2017 Actual submission date: 30/06/2017

Disclaimer of warranties and limitation of liabilities

This document has been prepared by MEDEAS project partners as an account of work carried out within the framework of the EC-GA contract no 691287.

Neither Project Coordinator, nor any signatory party of MEDEAS Project Consortium Agreement, nor any person acting on behalf of any of them:

(a) makes any warranty or representation whatsoever, express or implied,

  (i). with respect to the use of any information, apparatus, method, process, or similar item disclosed in this document, including merchantability and fitness for a particular purpose, or

  (ii). that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or

  (iii). that this document is suitable to any particular user's circumstance; or

(b) assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if Project Coordinator or any representative of a signatory party of the MEDEAS Project Consortium Agreement, has been advised of the possibility of such damages) resulting from your selection or use of this document or any information, apparatus, method, process, or similar item disclosed in this document.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

Document info sheet

Lead Beneficiary: University of Valladolid

WP: 4, Model building and models implementation

Task: 4.1c. Country-level model; 4.2. Implementation of the scenarios and pathways proposed in WP3 on the TIMES model for Austria; 4.3. Implementation of the scenarios and pathways proposed in WP3 on the LEAP model for Bulgaria

Authors:

UVa: David Álvarez Antelo, Ignacio de Blas, Iñigo Capellán-Pérez, Óscar Carpintero, Carlos de Castro, Fernando Frechoso, Luis Fernando Lobejón, Pedro L. Lomas, Margarita Mediavilla, Luis Javier Miguel, Jaime Nieto, Gonzalo Parrado, Paula Rodrigo González

BSERC: Angel Nikolaev, Lulin Radulov

AEA: Martin Baumann, Lukas Eggler, Angela Holzmann, Christoph Ploiner

Dissemination level : Public

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

Annex 1: Exogenous energy intensity targets

In previous versions of MEDEAS, the evolution of energy intensities was estimated dynamically based on historical trends and the changes that can be produced on them due to the market conditions of the final energy types or due to the energy policies.

As in the case of the global medeas_w 1.3 version and medeas_eu 1.2 version, a modification in the country-level models (medeas_bg1.2 and medeas_at1.2) has been introduced and the energy intensity targets in a given year can be defined exogenously, so that the model evolves towards them. Thus, for the energy intensities (sectoral and household), three options can be selected in the model:

1) The energy intensities remain constant with the value of the last historical year.
2) Dynamic evolution of energy intensities (option selected by default).
3) Introduction of energy intensity targets for a specific year, so that the model evolves towards it.

At the same time, two options for the energy intensity target can be selected:

1) The energy intensity target is directly chosen by the user according to particular targets.
2) The energy target is defined by the variation of the energy intensity over the value of a specific year.

In the case that specific energy intensity targets are defined for a certain year, the scarcity perception and fuel replacement activation can produce a different result not arriving to the objective or arriving previously.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

Annex 2: Modelling of fuel replacement

How to measure the scarcity or abundancy of natural resources has been a controversial issue in economics for a long time (Neumayer, 2000). Ecological Economics criticizes the mainstream approach considering prices as a reliable indicator of scarcity of natural resources, given its theoretical and empirical weaknesses. Energy and mineral prices are subject to multiple influences (institutional framework, oligopolistic market structure, etc.), which prevent perfect competition to happen neither in the short nor long-term (Norgaard, 1990; Reynolds, 1999). Moreover, given the inertia and rigidities in the productive processes highly dependent on natural resources, important adjustments in the economic system are produced with *quantity* changes (instead of prices), as post-Keynesian approaches have highlighted (Lavoie, 2014). For both reasons, MEDEAS applies an alternative "biophysical" perspective to model fuel replacement which takes into account the evolution of the extraction of natural resources and their physical availability/scarcity (Campbell and Laherrère, 1998; Valero et al., 2014).

There is a first allocation mechanism in MEDEAS models at primary energy level for the generation of electricity, assuming that, given infrastructure available, different fuels can contribute to the electricity mix. Given that priority is given by default to renewable energy sources and nuclear, the remaining supply is allocated between oil, natural gas and coal. The adjustment for heat is modelled directly at final energy level given that the large majority of heat is not traded and is thus subject to the infrastructure at final user level.

There is a second allocation mechanism in MEDEAS models at final energy level, by replacing those fuels, which are scarcer, by fuels that are not/less scarce. This is performed through the variation of the final energy intensities. This variation is modelled on top of the exogenous trends for its future variation set by the user through the inputs.xlsx (see MEDEAS deliverables D4.1 (Capellán-Pérez et al., 2017), D4.2 (de Blas Sanz et al., 2018) and D4.3 (Álvarez Antelo et al., 2018)). Additionally, fuel scarcity also has the effect of accelerating efficiency use for this fuel. These fuel replacements and efficiency improvements are limited, in the standard version of the model, by the historical maximum from WIOD time-series (Genty et al., 2012; Timmer et al., 2012)).

Fuel scarcity for fuel i (primary and final) is defined as follows:

$$scarcity_i(t) = 1 - abundance_i(t)$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

$$abundance_i(t) = 1 - \frac{demand_i(t) - supply_i(t))}{demand_i(t)}$$

The perception of inter-fuel energy scarcities are modelled through the balance of the effect of the sensitivity to scarcity and the forgetting factor (see Figure 1 for the loop diagram of the modelling for final energy scarcities).

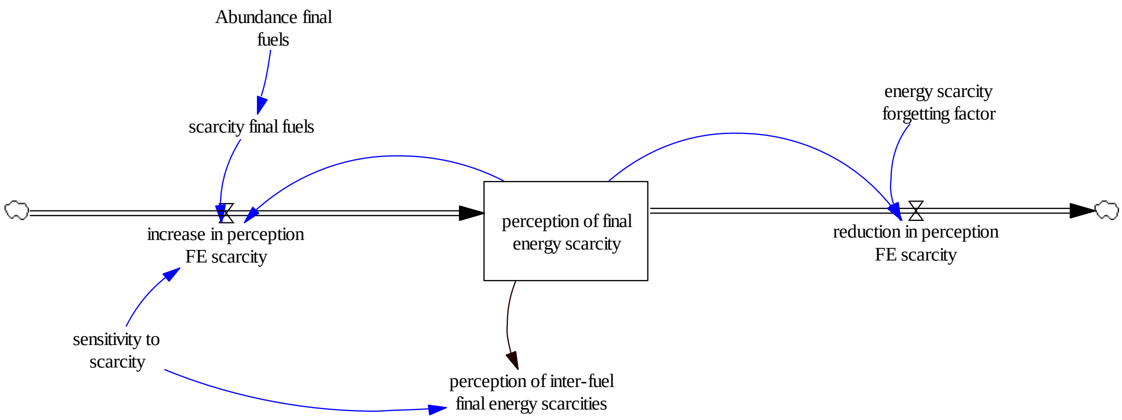

Figure 1: Loop diagram of the modelling of the perception of inter-fuel final energy scarcities in MEDEAS. Own elaboration.

Both parameters can be edited by the user through the inputs file excel sheet:

- **Sensitivity to scarcity**: this parameter reflects that economic agents and households may have different perceptions of scarcity and accordingly react differently (i.e., at a different speed) in a situation of fuel scarcity. 3 levels are pre-defined for the user: low, middle and high.

- **Forgetting factor**: this parameter reflects that the perception of scarcity of the economic agents is also influenced by the persistence in the memory of past events of fuel scarcity. A by default value of 5 years is assumed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

Annex 3: Imports

Since MEDEAS-World (medeas_w) logically does not use trade, all the energy consumed is produced at the same regional level. Thus, net energy final consumption could not trespass the biophysical boundary imposed by energy availability in the same region (the entire world). From the MEDEAS-EU model (medeas_eu), it is not so simple, and it can also be applied to the country-level models. Boundaries can be artificially trespassed thanks to international trade, i.e. countries are able to consume more energy than produced. In fact, this is the current situation for most of the EU countries, and one of the main vulnerabilities in a context of world energy depletion. Hence, in order to take into account of global limits on energy consumption, different scenarios can be applied, as summarised in Table 1.

Table 1. Energy-economy feedback under different scenarios. Source: own elaboration.

Scenarios	Features
No limits	Countries can import energy limitless.
Current shares	Countries can import energy at current levels.
Fixed share	Countries can import energy with a user-fixed level.

In the 'No limits' scenario, there are no restrictions for European countries. Thus, European countries are allowed to import as much energy as they need to consume, regardless if they are consuming even the 100% of world energy for each type. On the contrary, the three other scenarios do impose boundaries to energy consumption.

Furthermore, 'Current shares' implies that, for each final energy source, European countries can import no more that the current proportion of their consumption over the world supply.

Finally, 'Fixed share' let the user to fix that proportion at his or her preference, no matter if over or under current levels.

How the energy consumption is distributed amongst regions is also a measure of equality and has deep implications on the issue of a fair transition.

Pg. Marítim de la Barceloneta, 37-49 08003 Barcelona www.medeas.eu info@medeas.eu T +34 93 230 95 00 F +34 93 230 95 55

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

Annex 4: Public transportacion alternative scenario

MEDEAS country-level models have also been modified in order to include the possibility of public transportation substitution of private cars, as suggested in the MEDEAS general assembly in February 2019.

As stated in Deliverable 4.1, Medeas models separates commercial transportation (Inland, Air and Water Transport sectors) and households transport activity. For Inland Transport and Households transportation the vehicle shift is considered as well as the general efficiency improvement for all sectors. In the country-level models (as well as in Medeas_w and Medeas_eu) household vehicles are organized into six types: liquid, electric, hybrid and gas 4 wheelers and liquid and electric 2 wheelers.

In versions Medeas_bg.v1.1 and Medeas_at.v1.1, a new type has been introduced in order to model the substitution of private cars by public transportation, non motorized transport and electric bikes (or very light electric vehicles). All these alternatives are included into a new subscript called *subst* which accounts for the percentage of four wheel cars that are substituted by those alternatives and is added to the subscripts already mentioned. This new type is treated as the previous ones: via policies that state a final desired percentage in the target year (*T fin H veh*) and grow linearly from cero value. The substitution of present private cars by public transportation or electric bikes that we consider is only the one added to present use of these means of transportation, thefore, its initial percentage is zero.

The following policies have been added to quantify this new policy (as named in inputs.xlsx and Vesim files):

- **Percent substitution in year Tfin over 4wheel vehicles** (*P percent subst*) Is the desired percent of four wheelers substituted by other forms of urban mobility such as very light electric urban vehicles (ebikes), waking and public transportation at the ending year of the policy (*T fin H veh*). This substitution has a limit, since it can only be applied to urban mobility (50%).
- **Percent of ebikes out of substitution** (*P percent ebikes out of subst*) is the desired percent of the substitution that is obtained with electric bikes at the final year of the policy (*T fin H veh*).
- **Percent of public transportation out of substitution** (*P percent public out of subst*) is the desired percent of the substitution that is obtained with public transportation at the final year of the policy.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

Based on these desired policies, the model calculates the percentage of vehicles substituted out of the total amount of households vehicles (two and four wheelers) in the Vensim variable *Percents H vehicles*. And, based on this, the number of electric bikes, the batteries needed for them and the change in the energy intensity for electricity that is due to it. The size of the batteries for electric bikes is set to one tenth of the one for two wheelers, proportional to the average weight of these vehicles (Sanz et. al. 2014).

Warning and limitations of the model

In the earlier versions of the country-level models, the policies applied to transportation only where the change of vehicles and an increase in the general efficiency of the sector. A massive shift to public transportation was not modelled, and one of the main reasons for this omission is the fact that the feedback between the reduction of car use and the activity of the automobile-related economic sectors cannot be neglected and, at present, those kinds of economic demand-base feedbacks are not considered in the economic modules of Medeas. For the specific case of the country level models, this feedback can be ignored, since the effect of one particular country on the world automobile industry is small, that is the reason why the public transportation policy has been introduced in the country-level models with this modification (but not in the EU model).

But, the massive introduction of public transportation has got another feedback in the economy that cannot be neglected at country level: the increment on the activity of the Inland Transportation sector due to the increment of the activity of trains and buses. This feedback has not been introduced in the Medeas_bg.v1.1 and Medeas_at.v1.1 models, therefore the model gives good estimations of the energy savings of this policy but a not so good estimation of the economy variables related to it. The introduction of this feedback is not straightforward, since the increment on the transport economic activity due to the substitution of a certain number of cars is not a parameters easy to calculate.

On the other hand, since the changes in the intensities in Medeas are related to the changes in percent of vehicles using the following formulas (see section 2.14 of Medeas D4.1):

$$\frac{dI_{liq\ inland\ t}}{dt} = CX_{HV} \cdot \frac{d}{dt}\%HV_{liq} + CX_{LV} \cdot \frac{d}{dt}\%LV_{liq} + CX_{bus} \cdot \frac{d}{dt}\%bus_{liq} + CX_{train} \cdot \frac{d}{dt}\%train_{liq}$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

$$\frac{dI_{elec\ inland\ t}}{dt} = CX_{LV} \cdot sr_{elec\ LV} \cdot \frac{d}{dt}\%LV_{elec} + CX_{bus} \cdot sr_{elec\ bus} \cdot \frac{d}{dt}\%bus_{elec} + CX_{train} \cdot sr_{elec\ train} \cdot \frac{d}{dt}\%train_{elec}$$

$$\frac{dI_{gas\ inland\ t}}{dt} = CX_{HV} \cdot sr_{gas\ HV} \cdot \frac{d}{dt}\%HV_{gas} + CX_{LV} \cdot sr_{gas\ LV} \cdot \frac{d}{dt}\%LV_{gas} + $$

$$+CX_{bus} \cdot sr_{gas\ bus} \cdot \frac{d}{dt}\%bus_{gas}$$

Being HV the total number of heavy vehicles, LV the total number of light cargo vehicles, Bus the number of buses, and Train the number of trains. $\%HV_{liq4w}, \%LV_{liq}, \%bus_{liq}$ and $\%train_{liq}$ are the percentages of liquid vehicles of each type; $use_{HV}, use_{LV}, use_{bus}, use_{train},$ the average use of each vehicle in terms of Km/(year· vehicle) and $EF_{HV\ liq}$, $EF_{LV\ liq}, EF_{bus\ liq}, EF_{train\ liq}$ the technical efficiencies of vehicles expressed in terms of the energy per Km.

And we assume that the use and the number of vehicles per unit of economic activity $X_{t\ in}$ is kept constant and the only change is the variation of the type of vehicle, therefore, the following values can be considered constant:

$$CX_{HV} = \left(\frac{HV \cdot use_{HV} \cdot EF_{HVliq}}{X_{t\ in}}\right); \quad CX_{LV} = \left(\frac{LV \cdot use_{LV} \cdot EF_{LVliq}}{X_{t\ in}}\right) \ ;$$

$$CX_{bus} = \left(\frac{Bus \cdot use_{bus} \cdot EF_{bus\ liq}}{X_{t\ in}}\right); \quad CX_{train} = \left(\frac{Train \cdot use_{train} \cdot EF_{train\ liq}}{X_{t\ in}}\right)$$

If a policy of massive public transportation is introduced, constant CX_{bus} is likely to change, since the use of buses and the number of buses per each dollar of the economic activity of the Inland Transportation sector will not remain constant, and we have no idea on how this is evolving.

Therefore, the policy of substitution of household cars by electric bikes, non-motorized modes and public transportation that has been introduced in Medeas_bg.v1.1 and Medeas_at.v1.1 has to be used carefully, taking into account that its results are not very accurate, especially when strong introduction of public transportation is performed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

References

Álvarez Antelo, D., de Blas Sanz, I., Capellán-Pérez, I., Carpintero Redondo, Ó., De Castro, C., Frechoso, F., Lobejón, L.F., Lomas, P.L., Mediavilla, M., Miguel, L.J., Nieto, J., Parrado, G., Rodrigo González, P., 2018. D4.3 MEDEAS Model and IOA implementation at country level: the cases of Austria and Bulgaria (Deliverable MEDEAS project, http://www.medeas.eu/deliverables). GEEDS, University of Valladolid.

Campbell, C.J., Laherrère, J., 1998. The end of cheap oil. Scientific American 278, 60–65.

Capellán-Pérez, I., de Blas, I., Nieto, J., De Castro, C., Miguel, L.J., Mediavilla, M., Carpintero, Ó., Rodrigo, P., Frechoso, F., Cáceres, S., 2017. MEDEAS Model and IOA implementation at global geographical level (Deliverable MEDEAS project, http://www.medeas.eu/deliverables No. D4.1). GEEDS, University of Valladolid.

de Blas Sanz, I., Capellán-Pérez, I., Carpintero Redondo, Ó., De Castro, C., Frechoso, F., Lobejón, L.F., Lomas Huertas, P.L., Mediavilla, M., Miguel, L.J., Nieto, J., Rodrigo, P., 2018. MEDEAS Model and IOA implementation at European geographical level (Deliverable MEDEAS project, http://www.medeas.eu/deliverables). GEEDS, University of Valladolid.

Genty, A., Arto, I., Neuwahl, F., 2012. Final database of environmental satellite accounts: technical report on their compilation. WIOD Deliverable 4.6, Documentation, downloadable at http://www.wiod.org/publications/source_docs/Environmental_Sources.pdf.

Lavoie, M., 2014. Post-Keynesian Economics: New Foundations. Edward Elgar Publishing.

Neumayer, E., 2000. Scarce or Abundant? The Economics of Natural Resource Availability. Journal of Economic Surveys 14, 307–335. https://doi.org/10.1111/1467-6419.00112

Norgaard, R.B., 1990. Economic indicators of resource scarcity: A critical essay. Journal of Environmental Economics and Management 19, 19–25. https://doi.org/10.1016/0095-0696(90)90057-6

Reynolds, D.B., 1999. The mineral economy: how prices and costs can falsely signal decreasing scarcity. Ecological Economics 31, 155–166. https://doi.org/10.1016/S0921-8009(99)00098-1

Sanz, A., Vega, P., Mateos, M., 2014. Las cuentas ecológicas del transporte en España. Libros en Acción, Madrid.

Timmer, M., Erumban, A.A., Gouma, R., Los, B., Temurshoev, U., de Vries, G.J., Arto, I., Genty, V.A.A., Neuwahl, F., Francois, J., others, 2012. The world input-output database (WIOD): contents, sources and methods. Institue for International and Development Economics.

Valero, Antonio, Carpintero, Ó., Valero, Alicia, Calvo, G., 2014. How to account for mineral depletion. The exergy and economic mineral balance of Spain as a case study. Ecological Indicators 46, 548–559. https://doi.org/10.1016/j.ecolind.2014.07.021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287