REVENUE OF GLOBAL ENERGY SYSTEM MODELING BASED ON REMOTE SENSING DATA WITH FOCUS ON RENEWABLE ENERGY RESOURCES – A CASE STUDY

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KEYWORDS: renewable energy, spatial optimization, remote sensing

ABSTRACT

The paper presents an approach that bridges the gap between the consideration of spatial correlations in future energy systems and common energy system modelling approaches with a focus on forecasting the entire energy system. Therefore the energy system model TASES (Time And Space resolved Energy Simulation) has been developed in order to tackle best all relevant geographical correlations in energy systems. Especially renewable energy sources are often location dependent and highly intermittent. The model is a snap shot model focusing on one year, including seasonal and day/night variations among the region of interest. It outlines the optimal energy system setup in terms of locations for PV, wind turbines or biomass power plants also with respect on an optimal transmission grid as part of the entire system. Remote sensing data are used to derive spatial indicators which are utilized as geographic discrete parameters in the TASES model. Scope of the outlined model framework is the analysis especially of the impact triggered by spatially varying system parameters on the entire energy system. This is particularly relevant with considering renewable energy resources. That gives the opportunity to study spatial infrastructure setups of the energy system with respect to single locations. A first case study linked to a MESSAGE long-term model run is elaborated and discussed.

INTRODUCTION

Our current energy system is mainly based on fossil fuels and nuclear power. The spatial context in such a system is secondary since transport efforts are marginal and supply and demand locations can be easily matched. That is also reflected in most system modelling approaches in terms of not paying further attention to spatial correlations. Main focus is dedicated to economical correlations not triggered by spatial indicators. The current transition of the energy system towards a higher share of temporally and spatially highly disperse renewable energy resources make it necessary to consider spatial correlations between different resources and also demand structures. Paying attention to these correlations on the entire system as part of one objective function is a raising issue and not yet treated in many studies.

The outlined TASES model approach claims to enrich economically driven forecast energy system models – usually distinguishing only several regions as aggregated clusters – with spatially relevant impacts derived from remote sensing data as part of the objective function. The spatially relevant impacts are applied in the model approach to identify optimal locations for solar PV, wind power and biomass plant installations as part of the entire energy system in order to match best the electricity demand. The approach has been applied in a scenario comprising the entire globe in order to figure out possible correlations among different supply and demand locations connected via a grid infrastructure. Remote sensing data are utilized and interpreted in terms of a spatially discrete parameterisation for this model approach.

FRAMEWORK

In the centre of the framework is the TASES model. It is a linear optimization model especially dedicated to identify location and time depending correlations in the energy system on the global scale in individual snap shot scenarios (Biberacher 2008). Therefore it treats individual grid cells as smallest geographical unit. These cells can interact with their neighbours. The size of these grid cells is 2.5 degree in longitude and latitude. For each grid cell the individual temporal electricity demand and supply load patterns are considered. That makes it possible to pay attention to temporally discrete coverage rates, what is of major interest with respect to high shares of renewable energy carriers in the energy system. The energy balance in each grid cell is influenced by energy supply (triggered by plant installations) within the grid cell and by the imports from and the exports to neighbouring grid cells (triggered by network installations). For each grid cell the model identifies the optimal setup in terms of renewable power installations that satisfy given constraints and fit best in the context of the entire energy system setup by minimizing total system costs.

In order to figure out spatially triggered impacts and correlations in the electricity supply system the following parts of the entire energy system are considered in a TASES scenario run:

- PV installations
- Wind turbine installations
- Biomass plant installations
- Electricity demand

Since decoupled snap shot scenarios have only limited expressiveness in long term planning the TASES model is linked to results from a MESSAGE long term scenario run. To fix the parameterisation for a TASES scenario run, inputs from a MESSAGE scenario are passed over to the TASES model. Additionally TASES uses geographical indicator datasets derived from remote sensing data (see figure 1).

Figure 1. Model framework and data flows

MESSAGE is a bottom-up multi regional optimization model that forecasts the development of the global energy system aggregated to single world regions. It is a systems engineering optimization model used for medium- to long-term energy system planning, energy policy analysis, and scenario development (Messner and Strubegger, 1995). The model provides a framework for representing an energy system with all its interdependencies from resource extraction, imports and exports, conversion, transport and distribution, to the provision of energy end-use services and transportation. Scenarios are developed by MESSAGE through minimizing total systems costs under the constraints imposed on the energy system. The model provides the installed capacities of technologies, energy outputs and inputs, energy requirements at various stages of the energy systems, costs, emissions, etc.

Results from MESSAGE in terms of future electricity demand and installed capacities for individual world regions at a certain future milestone year are taken as constraints for a TASES model run. Remote sensing data interpreted as spatial indicators deliver the relevant geographic information needed to compute TASES scenarios. These spatial indicators are the availability of renewable energy carriers in terms of potentials and limitation constraints in each grid cell for instance.

ASSUMPTIONS AND DATASETS

The 2.5 degree grid cell resolution is outlined in figure 2. Grid cells are assigned to one of the 11 regions defined in the MESSAGE multi regional energy model.

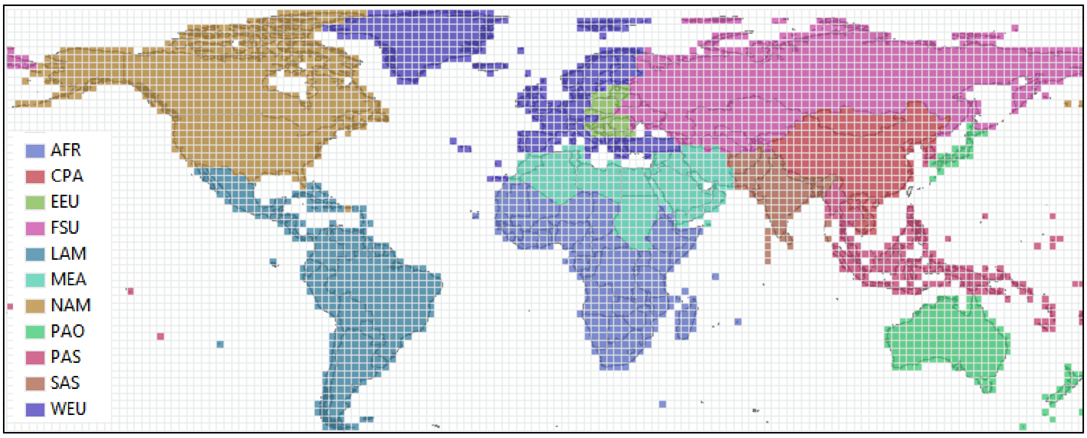

Figure 2. Grid basis of TASES model approach merged with MESSAGE multi region approach.

Scope of the outlined setup is the consideration of both energy system settings that are not triggered by the exact geographical location but related to an individual MESSAGE scenario region (e.g. conventional conversion capacities) and those that are highly dependent on their geographic location and therefore assigned to single grid cells (e.g. renewable energy conversion capacities).

In order to find out where electricity demand as well as potentials and limiting constraints for biomass plants, wind turbines and PV installations on a grid cell level are located, remote sensing data are utilized and interpreted. In table 1 the utilized data sets are outlined.

Table 1. Utilized geographical and remote sensing data sets.

Dataset	Resolution	Source
Earth city lights	5 sqkm	http://visibleearth.nasa.gov/view.php?id=55167 (NASA)
Terrain slope	30 arc sec	http://www.iiasa.ac.at/Research/LUC/Products-Datasets/global-terrain-slope.html (IIASA)
GLC 2000	1 sqkm	http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php (JRC)
NASA SSE	1 arc deg	http://eosweb.larc.nasa.gov/sse/ (NASA)
WWA	2.5 arc deg	http:// www.sander-partner.ch/ (Sander&Partner)
G4M	1 arc deg	IIASA internal dataset

In a first step generally suitable areas for PV- and wind installations are identified, following the assumptions outlined in table 2. Not all of the generally suitable areas are assumed to be used and a share is defined. The PV and wind potentials are then generated by processing the used share of suitable areas with resource data (table 2). The potentials are aggregated to the 2.5 degree grid cells and serve as the parameter settings for the TASES model.

Table 2. Resource datasets and land-use constraints for PV and wind turbine installations.

	Resource data	**Excluded areas**	**Suitable area**	**Used share of suitable area**
PV in urban area	Global horizontal irradiance, NASA SSE		Urban areas (GLC 2000)	1 %
PV on open area	Global horizontal irradiance, NASA SSE	Protected areas (WDPA), slope > 2.1 % GHI < 1800 kWh/m²/year	Agricultural areas (GLC 2000) Grassland (GLC 2000) Bare and sparsely vegetated areas (GLC 2000)	0.03 % 0.03 % 33 %
Wind Onshore	World Wind Atlas	Protected areas (WDPA)	Bare and sparsely vegetated areas (GLC 2000) Grassland (GLC 2000) Shrub cover (GLC 2000) Mosaic (grass, shrubs, trees) (GLC 2000) Agricultural areas (GLC 2000) Forest (GLC 2000)	33 % 3 % 3 % 3 % 3 % 3 %

In terms of sustainable biomass potentials for energetic purposes growth results from the G4M model of IIASA are taken as proxy. The G4M model focuses on sustainable forestry growth rates as output. The results are also shown in figure 3.

Modelling the electricity demand is based on the assumption that geographical distribution of electricity is reflected by luminescence of earth at night. The luminescence value is considered as indicator that correlates linearly with the electricity demand at a certain location. Although that is a rough assumption and does not reflect exactly the geographical distribution of electricity demand it is a good approximation. Hence luminescence values are summed up to the 2.5 degree grid size (see figure 3) and normalized by the electricity demand assumptions made in the MESSAGE scenario for the individual world regions for the year 2020 (see table 3).

In addition to the geographic discrete settings relevant for the TASES model also system settings on a regional aggregated scale are treated. That includes all parameters describing conversion technologies. The technology database in the model is kept quite basic. For each renewable energy potential only one general conversion technology is considered in the model. Table 3 shows the installed capacities of technologies as assumed in a MESSAGE scenario run for the year 2020.

Table 3. Region specific parameters for the year 2020 from MESSAGE model.

		AFR	**CPA**	**EEU**	**FSU**	**LAM**	**MEA**	**NAM**	**PAO**	**PAS**	**SAS**	**WEU**
El. Demand in EJ/year		2.7	14.7	1.8	4.4	4.4	3.9	13.8	4.1	5.9	5.2	10.2
Installed Capacity in GW	Biomass plant		0.33	1.06	-	4.58	-	10.34	4.69	-	1.41	8.62
	PV plant	15.60	-	-	-	0.05	0.40	1.60	3.00	9.16	1.47	25.86
	Wind turbine		31.90	-	0.07	-	1.63	61.55	8.85	6.60	21.51	81.79

In order to pay attention to spatial correlations in the energy system on the global scale, that are triggered by the interconnection of different time zones and seasonal aspects the model framework distinguishes load pattern for three type days with respect to winter, summer and an intermediate season in 4 hour time steps (figure 4).

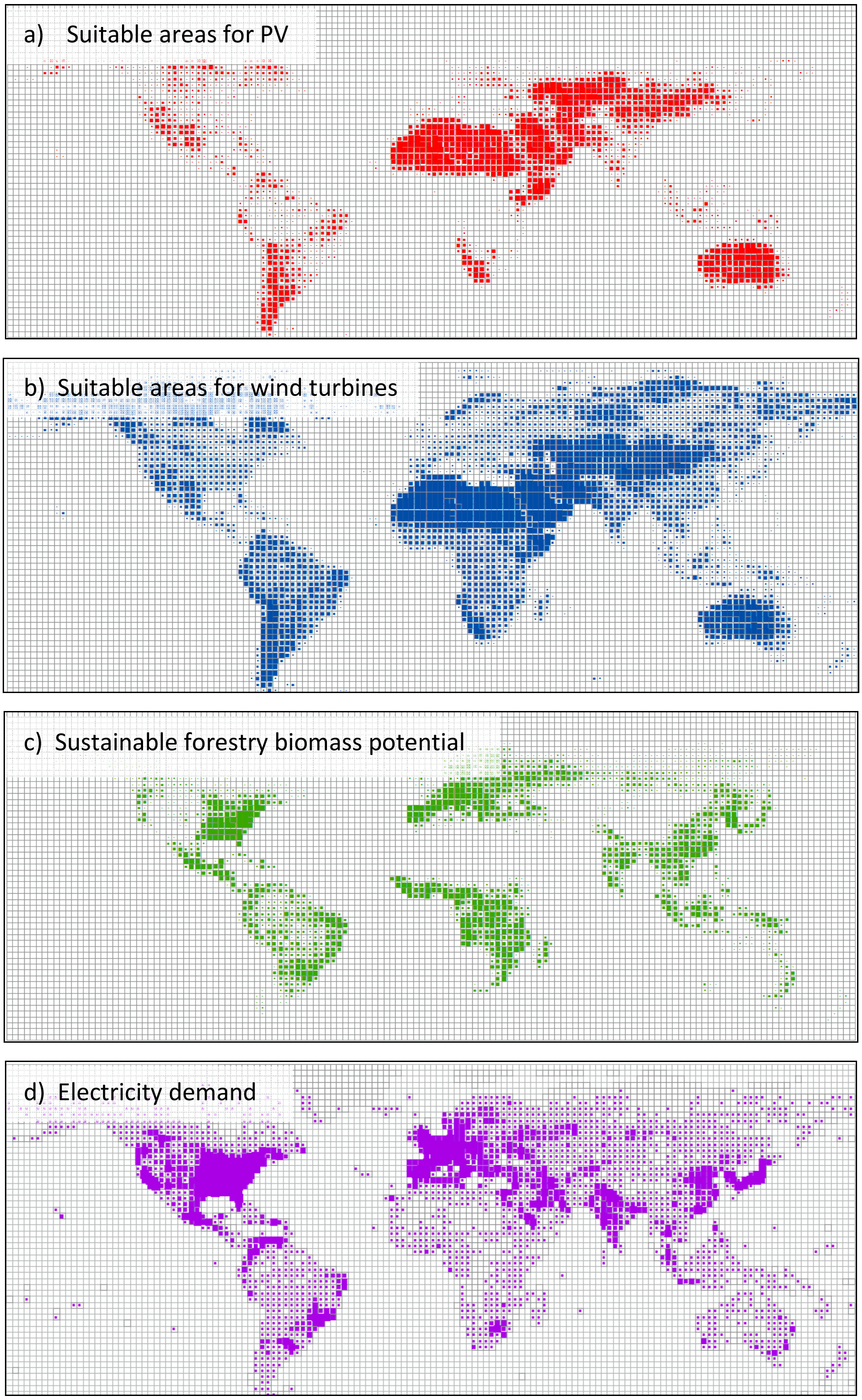

Figure 3. Renewable energy resources and electricity demand on a 2.5 deg grid basis for the entire globe.

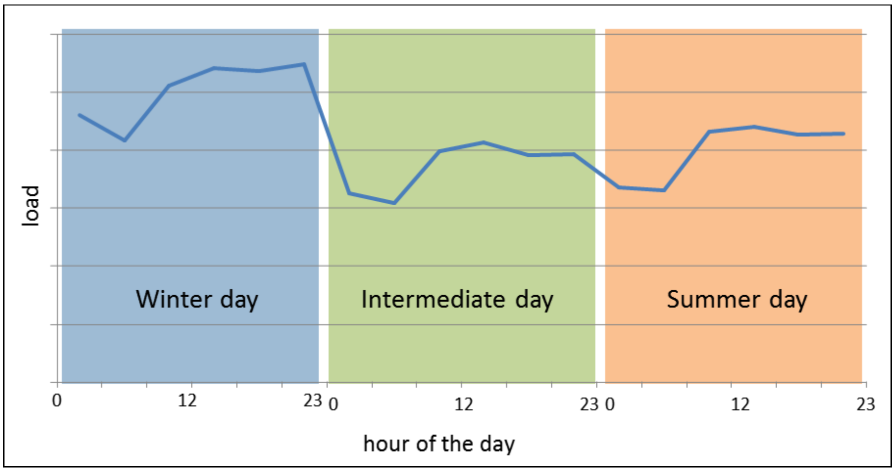

Figure 4. Time slices considered in TASES model approach.

Load patterns for the electricity demand are derived from hourly load pattern of the UCTE grid (ENTSOE 2012) Due to different time zones and seasons (northern- and southern hemisphere) this load adapted and assigned to each individual grid cell. Absolut demand values in each single grid cell are normalized with the demand value assigned to the MESSAGE region the grid cell belongs to.

Concerning the intermittent PV and wind power resources, availabilities for the same 4 hour time pattern have been elaborated for each single grid cell. 4 hourly irradiation values for each 2.5 degree grid cell have been recalculated from daily aggregated insolation harvests provided by NASA SSE data at a 1 degree spatial resolution for the entire globe (NASA SSE 2004). Intermittent wind potentials are recalculated to 4 hourly values from 6 hour wind speed values provided by the World Wind Atlas for each 2.5 degree.

Biomass potentials are not considered with a sub annual availability. Only the annual aggregated sustainable biomass potential in each individual grid cell taken from G4M model (Kindermann 2008) restricts the availability of biomass as energy resource. Needed transmission line capacities to balance individual grid cells are considered with a specific annually discounted investment cost of 17 $/MW/km/year.

OUTCOMES

The results of a TASES model run describe an optimized system setup with respect to spatial correlations within the identified MESSAGE model regions as well as on the global scale due to interregional transmissions. TASES delivers the following results which:

- installed capacities for PV, wind power and biomass plants in each single grid cell
- installed transmission line capacity to transfer electricity produced by PV, wind or biomass to neighbouring grid cells
- load of biomass plants in each single grid cell
- load of transmission lines between neighbouring grid cells
- load of needed backup capacity for each region

Figure 5 outlines an optimal system setup as calculated with the MESSAGE model (a) and with the TASES model (b). In case (b) circles visualise the optimal plant installation capacity for PV, wind and biomass in each single grid cell. The arrows visualise needed transmission capacities to transport electricity provided by PV, wind or biomass in individual grid cells to grid cells with uncovered demands. The model setup satisfies the limitations given by the spatial indicators derived from remote sensing data.

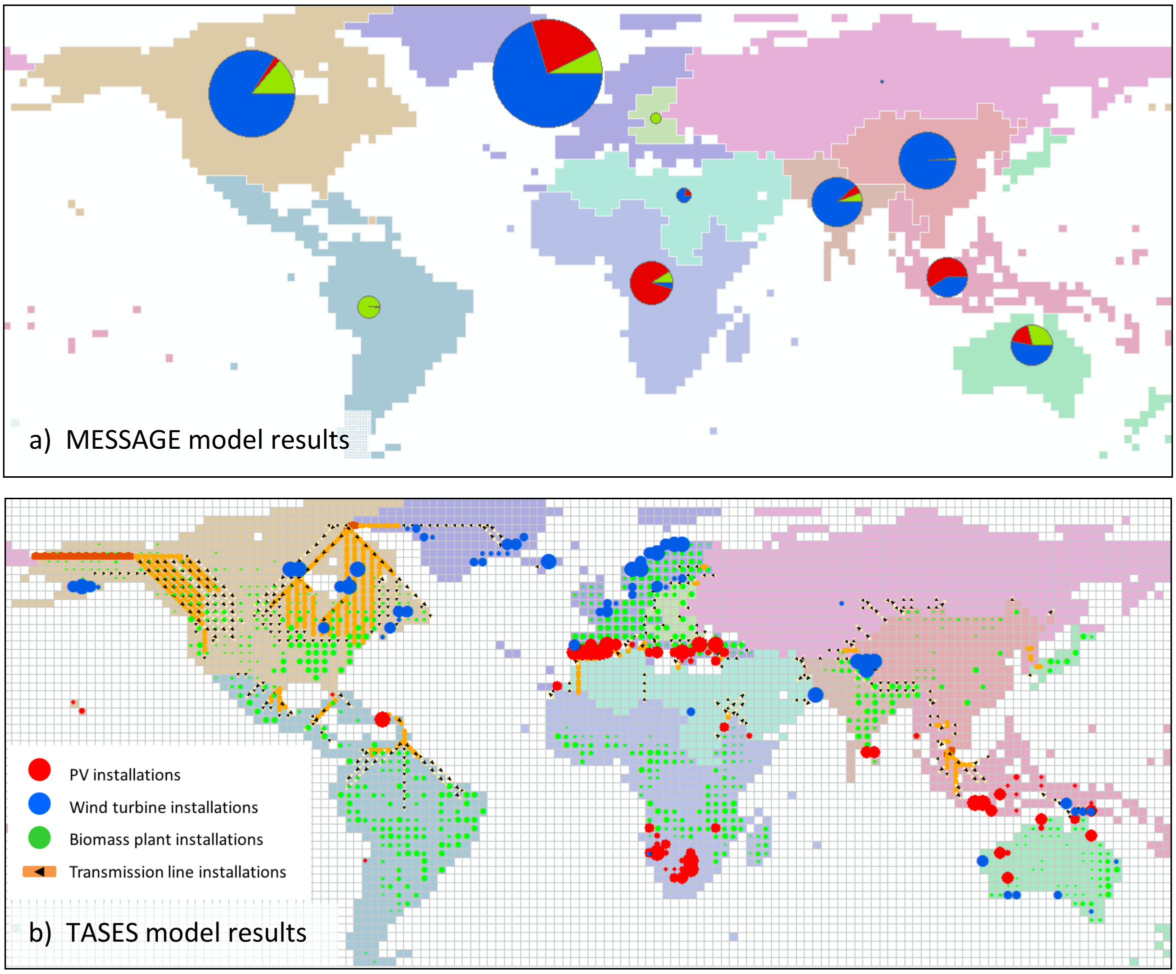

Figure 5. Global MESSAGE scenario (a) and related TASES scenario (b) with visualised optimal locations for wind turbine, PV and biomass plant installations in 2020.

The scenario in figure 5 (b) can be interpreted as snap shot for an optimal system setup in 2020 if it would be build up from scratch. It shows where PV, wind power and biomass plant installations would be optimally located in order to keep energy harvests high and transmission losses low. The related transmission line capacity needed to transfer electricity from identified optimal renewable energy plant locations to demand hot spots would sum up to 1175 TW*km.

CONCLUSION

With the TASES model regional aggregated results from multi-region energy system forecast models – here the MESSAGE model - are scaled down to individual location decisions. Single location decisions are considered with their impact on the entire energy system and therefore a deeper understanding of spatially driven correlations in the energy system is supported. This makes the model framework suitable to trigger decision making based on scenarios. Geographical indicator datasets derived from remote sensing data deliver the basis for such a location specific model approach which pays attention to geographical demand pattern as well as availability and land-use limitations for renewable energy resources within the optimization model TASES.

Hence the TASES model framework aims at bridging the gap between abstract model forecasts coming from long term energy system models and specific geographical influences on the system setup. By this TASES also supports sensibility studies regarding the impact of the parameter setting on an optimal geographical system setup. . Without the inclusion of remote sensing data such system study would lack the ability to proceed such geographic disperse scenarios. Especially in times of increasing renewable energy shares in the global energy system spatially specific impacts and correlations influence an optimal system setup significantly. Remote sensing data in that context provide a good – if not to say the only – database that supports a geographic concrete parameterisation on a supra regional scale. Therefore remote sensing data contribute to a high extent to supra regional energy system modelling with a focus on location based impacts and decisions.

ACKNOWLEDGEMENT

The work has been realized within the EnerGeo Project. The project is funded within FP7 and authors want to thank for the financial support by the Commission.

REFERENCES

Biberacher, M., 2008. GIS-based modeling approach for energy systems, International Journal of Energy Sector Management, Vol. 2 Iss: 3, pp.368 – 384

Biberacher, M. and Gadocha, S., 2009. GIS based model to optimize the utilization of renewable energy carriers and related energy flows. In: 18th World IMACS/MODSIM Congress, Cairns, Australia, 13-17 July, 2009, MSSANZ, Canberra, pp. 1915-1921.

Kindermann, G.E., McCallum, I., Fritz, S. and Obersteiner, M., 2008. A global forest growing stock, biomass and carbon map based on FAO statistics. Silva Fennica 42: 387-396.

Messner, S. and Strubegger, M., 2001. User's Guide for MESSAGE III, WP-95-69, International Institute for Applied Systems Analysis, Laxenburg, Austria. http://www.iiasa.ac.at/Research/ECS/docs/MESSAGE_man018.pdf (accessed 2012)

ENTSOE, 2012, Consumption Data, https://www.entsoe.eu/resources/data-portal/consumption/ (accessed 2012)