World Limits Model (WoLiM) 1.0

Model Documentation.

Technical Report

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World Limits Model (WoLiM) 1.0. Model Documentation

Abstract

This paper documents the first version of the "World Limits Model" (WoLiM 1.0), reporting the methodology and assumptions applied. This model is a E^3 simulation system dynamic model that focus on energy resource constraints and its implications for human socioeconomic systems at world aggregated level. In this version, it aims to describe the relationship Economy-Energy-Environment focusing on biophysical limits and deployment potential of renewable and non-renewable energies, as well as on anthropogenic Climate Change. It is in fact an improvement to the model presented in (Mediavilla et al., 2013) by widening the scope and adding complexity and features.

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Note: All dollars are in 2011 US$.

1. Introduction and objectives

WoLiM is a structurally-simple and transparent model which compares data from many different sources and helps viewing global panoramas. This model aims to deal with complex and non-linear systems subjected to constraints such as the human development in the natural ecosystems. In order to achieve it, we face different issues:

- Multidisciplinarity: the integration of knowledge from different sciences (economy, climate, geology, engineering, etc.)
- Uncertainty: in such complex systems, predictions become infeasible and modelers have to work with projections and scenarios.
- Interdependence among subsystems: since human activities unfold into natural ecosystems, feedbacks will be a key feature of the functioning of the whole system.

System Dynamics (SD) is a useful tool to deal with these issues and has already been applied to investigate their interactions (Dale et al., 2012a; de Castro, 2009; de Castro et al., 2009; Fiddaman, 2002; García, 2009; Meadows et al., 2004, 1972; Mediavilla et al., 2013).

While depletion studies for individual fuels are relatively abundant in the recent literature, few of them offer an integrated perspective of all energy sources considering potential future developments, and even less include the energy demand generated by the socio-economic system. On the other hand, many global Energy-Economy-Environment models have been developed (e.g. IPCC's Assessment reports, UNEP's Global Environmental Outlook), however, few of those models explicitly consider energy expansion constraints such as peakoil assuming that the demand of energy in the future will be supplied without significant restrictions. The model includes the exhaustion patters of non-renewable resources and the replacement by alternative energies, the estimations of development and market penetration of alternative technologies, the energy demand of World's economy under different socio-economic scenarios, the sustainable potential of renewable energies and the estimations of CO_2 emissions related to fossil fuel consumption, all of them viewed in a dynamic framework.

This 1.0 version allows to exploring the energy system and its climate change implications in detail. However, important features as feedbacks between the subsystems, the EROI consideration and other limits (e.g. water, minerals) are not included and are subject to current and future research.

2. Overview of the model WoLiM

In recent decades, many global energy-economy-environment models, most focusing into climate change analysis, have been developed (e.g. MESSAGE (Nakicenovic and Riahi, 2003), IMAGE (Bouwman et al., 2006), MERGE (Manne and Richels, 2004), etc.), some based on system dynamics (Bassi and Shilling, 2010; Davies and Simonovic, 2010; Fiddaman, 2002). However, few models explicitly recognize resource limits such as peak oil and relate them to the economic growth (Meadows et al. 1972, Meadows et al. 1992, de Castro et al. 2009, de Castro 2009a, García 2009, Mediavilla et al. 2013).

The WoLiM model, which continues previous work by (de Castro, 2009; de Castro et al., 2009; Mediavilla et al., 2013), tries to fill this gap by including both the energy sources (renewable and non-renewable) and the demand generated by the socio-economic system. It is based on a lineal structure (see Figure 1) which starts by choosing a scenario framework that consists of a set of socioeconomic and technological assumptions and policies that are integrated in a coherent and sensible way. The projection of the socio-economic drivers establishes the world energy demand. This demand is then disaggregated in sectors according to the different end-use sectors (electricity, industry, transport, etc.) and the energy demand of each sector is disaggregated into the demand by resources (liquid fuels, gas, electricity, etc.). These demands are compared with the production of each particular resource, which is limited by the geology-based peaks and the rates of technological substitution. Finally, the net CO2 emission and concentration levels are computed. Each scenario consists in a set of socioeconomic and technological assumptions and policies that are integrated in a coherent and sensible way (Scenario methodology is described in the section 4).

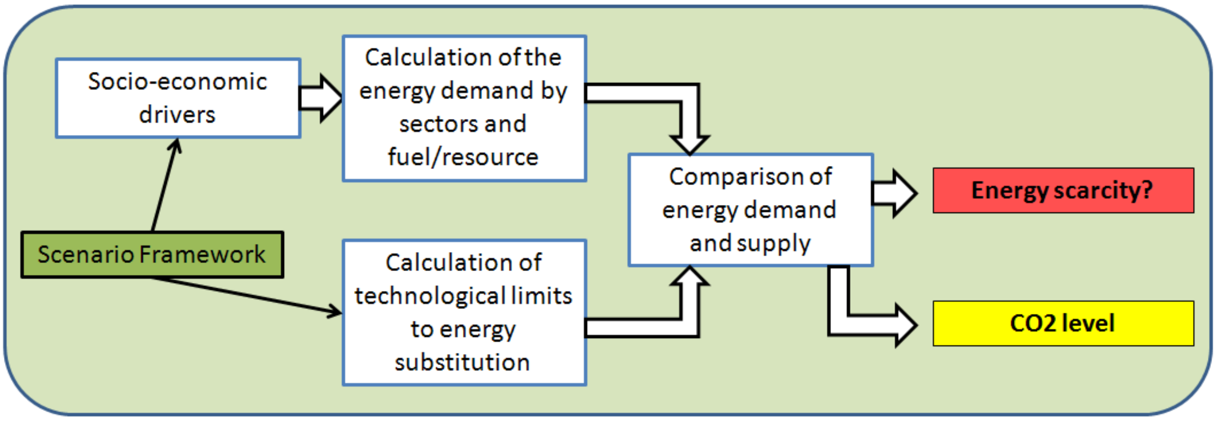

Figure 1: Basic logic functioning of the WoLiM model.

Although the model is based on System Dynamics (SD), this version is not a feedback-rich one as SD models tend to be. Some of the most obvious feedback loops are missing: e.g. it does not consider that the energy scarcity would influence the economy, i.e. the lack of energy would, for example, reduce economic growth (e.g. (Ayres et al., 2013; Hirsch, 2008)). This makes WoLiM a dynamic model of energy demand and technology trends versus physical restrictions.[1]

The reason for the simplification in this model version is the lack of consensus on the literature about the influence of energy scarcity on the future economic growth. Although some authors analyze this relationship (e.g. (Hirsch, 2008)), there is neither enough historical data at a global level to identify a tendency nor a well-developed and widely accepted theory on this topic. Most macroeconomic models pay very little attention to natural resources and, from our point of view, overestimate the capacity of technological substitution. Our studies are showing that the technological substitution, in particular the substitution of oil in this decade, is very difficult and does not seem possible in a demand-driven transition (de Castro et al., 2009; Mediavilla et al., 2013). On the other hand, the integration of this feedback tends to drive the system into collapse (Dale et al., 2012b; de Castro et al., 2009; Nel and Cooper, 2009). Therefore, prior to modeling an inadequate feedback, we decided not to include it. In this sense we can say that our model is conservative and its results can be seen as optimistic. The development of a more sophisticated model with a greater degree of energy-economy feedback would be desirable, and, at present, the authors are oriented towards the Ecological Economics in order to find theories that describe the real importance of natural resources in the economical process.

Despite these simplifications, the main advantage of WoLiM is the *large amount of data it integrates* and its structural simplicity, which makes it very transparent. It is not a model that intends to predict the future, since it only says *which future is not possible because of not being compatible with physical restrictions*, but, in fact, the ultimate objective of SD and scenario development is not to predict, but to understand the analyzed system (Meadows et al., 1972; Sterman, 2001).

[1] Another significant feedback such as the potential climate impact on the socioeconomy is neither considered (IPCC, 2007a; Smith et al., 2009).

The model functions as follows: the socioeconomic inputs GDP per capita[2] and Population are set exogenously. We interpret GDP not as a welfare indicator[3], but as a driver of economic activity that demands energy and materials. In fact, up to now, the world socioeconomic system has been unable even to approach absolute decoupling between GDP and resources (e.g. (Bithas and Kalimeris, 2013; Peters et al., 2011; UNEP, 2011)). The economy is organized in 4 aggregated sectors:

- Transportation: aviation, Road (freight and passenger), Rail, Pipeline transport, domestic navigation and world marine bunkers.
- Industry (excluding electricity)
- Buildings (excluding electricity)
- Electricity generation.

Each sector's energy demand is generated through sectoral Energy Intensities (details in **Section 3.2**). These sectoral energy demands are assigned to individual fuel contributions. We give priority to renewable energy, and the rest is proportionally divided between the non-renewable sources, maintaining the past ratios constant (20-years average values from *International Energy Outlooks*). Since energy transitions have been shown to be slow (Fouquet, 2010) and past fuel ratios by sectors have happened to change smoothly in the recent past (e.g. (WEO, 2012)), we consider the analysis valid for the medium term (2050). Thereafter, the model aggregates all sectoral energy demands by energy source and then compares them with the available resources.

The relationship between economy and energy in our model can be described as dual:

- **Demand-driven** if there is no restriction to the access of resources. In this case, the supply of energy is assumed to adjust to the estimated demand through the price mechanism until market equilibrium is reached.
- **Supply-driven** if the energy demand cannot be satisfied. In such a case, the estimated energy demand exceeds supply and an *energy scarcity* would appear. In order to deal with these divergences a set of indicators is set (see **Section 5**). Of course, in reality there would be an adjustment through a price increase to reach a new equilibrium. However, the model is still a useful tool to detect potential systemic-energy scarcity risks.

Finally, CO2 emission and concentration levels to 2100 are computed. Different scenarios and a wide range of alternative policies can be applied when running the model (see circled variables in **Figure 2**) by varying: sectoral energy-efficiency improvement, promotion of electric transportation, renewable production (electric, thermal, biofuels), non-renewable maximum extraction curves, nuclear expansion, Gas-to-Liquids (GTL) and Coal-to-Liquids (CTL).

Thus, this model enables to explore different scenarios of energy transition from a fossil-based system to a renewable energy one in the medium-term (until 2050), approximate date we consider the hypothesis employed could make sense. This model permits to focus into resource limitation, transition rhythms by identifying reasonable and feasible policies while ruling out others.

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[2] GDP in Market Exchange Rates. All dollars in the paper are in 2011 US$.

[3] We recall that GDP was not designed to measure social or economic welfare (Kubiszewski et al., 2013). The limitations of GDP as welfare indications are well known (e.g. (Jackson, 2009; van den Bergh, 2009)).

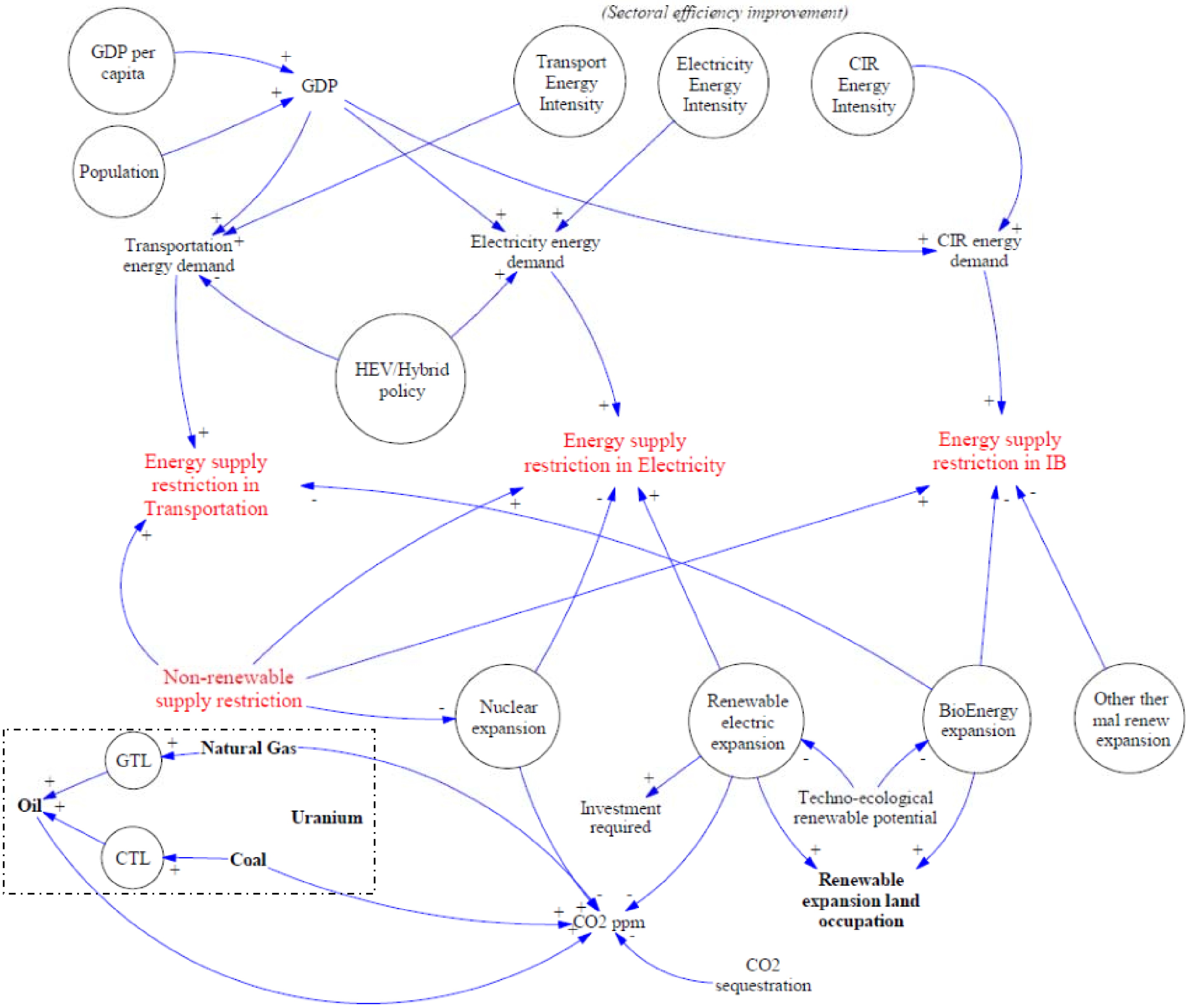


Figure 2: **Causal loop diagram of the model WoLiM 1.0 with its basic elements. Scenario elements and policies are circled. IB Industrial and Buildings sectors.**

3. Main Hypothesis

3.1. Energy resources modeling

In this section we discuss the assumed potential of energy resources until 2050. Nuclear fusion is not considered since the ITER and DEMO projects estimate that the first commercial fusion power would not be available before 2040 < http://www.iter.org >,thus at the very end of the timeline considered by this model.

3.1.1. Non-renewable resources

In order to make an estimate of the availability of fossil fuels, we have reviewed the main studies to date on this issue, only seeking those that not only refer to resources and reserves, but also take into account the limits to production rates (such as "peak oil") (Mediavilla et al., 2013). These studies (Aleklett et al., 2010; ASPO, 2009; EWG, 2008, 2007, 2006; Höök et al., 2010; Laherrère, 2006; Maggio and Cacciola, 2012; Mohr and Evans, 2009, 2011, 2009; Patzek and Croft, 2010; Zittel, 2012) provide production curves as a function of time, as in Figures 2, 3, 4 and 5, based on estimating the annual decline in wells and mines and supposing that, while the limits are not reached, production will tend to increase due to demand.

To be able to use these data in our model we must transform them, since it is a dynamic model that considers demand. Production depends on this (if the world economy goes into crisis and does not demand gas, for example, it will not be produced). Production will therefore be the minimum between the demand and the maximum production. To do this, we have integrated the curves of maximum production as a function of time and we have converted them into maximum production curves as a function of resources (see **Section 3.1.2**).

The literature was reviewed in order to select extraction profiles (depending on time) calculated following approaches that account for the physical restrictions (e.g. Hubbert Theory), presented in (Mediavilla et al., 2013). This review was updated for the WoLiM 1.0 version including the following studies: (EWG, 2013; Laherrère, 2010; Maggio and Cacciola, 2012; Mohr, 2012; Zittel, 2012). For comparison purposes, projections from the International Energy Agency are also represented (WEO, 2012).

Oil

Conventional and unconventional[4] oil resources are disaggregated in the model. In fact, while the estimations for conventional oil tend to converge for similar URR (de Castro, 2009; Maggio and Cacciola, 2012; Sorrell et al., 2009) the highest uncertainty is on the future development of unconventional oil (Mohr and Evans, 2010). Thus, we selected the middle scenario of (Maggio and Cacciola, 2012) (see **Figure 3**).

In spite of the uncertainty associated to the unconventional oil URR, its main issue, in the words of (Laherrère, 2010), is that "*the size of the tank does not matter, it is only the size of the tap*". In fact, due to the viscosity and physical properties of unconventional oils, pumping becomes more energy consuming and slower. As an example, (Mohr and Evans, 2010) estimate 3 (very) different URR extraction scenarios. Although results vary at the end of the century, the difference in the extraction level in 2050 between the highest and the lowest case is inferior to 15%. Thus, we consider a URR of 750 Gboe after a review of other studies (ASPO, 2009; de Castro, 2009; Guseo, 2011; Laherrère, 2006). Unconventional oil extraction is modeled following the approach used in (de Castro et al., 2009). We consider a "Best Guess" case, extrapolating the 4.5% annual growth past trend and an optimistic "High Case" of 6.6% annual growth as estimated by (Grushevenko and Grushevenko, 2012; Söderbergh et al., 2007).

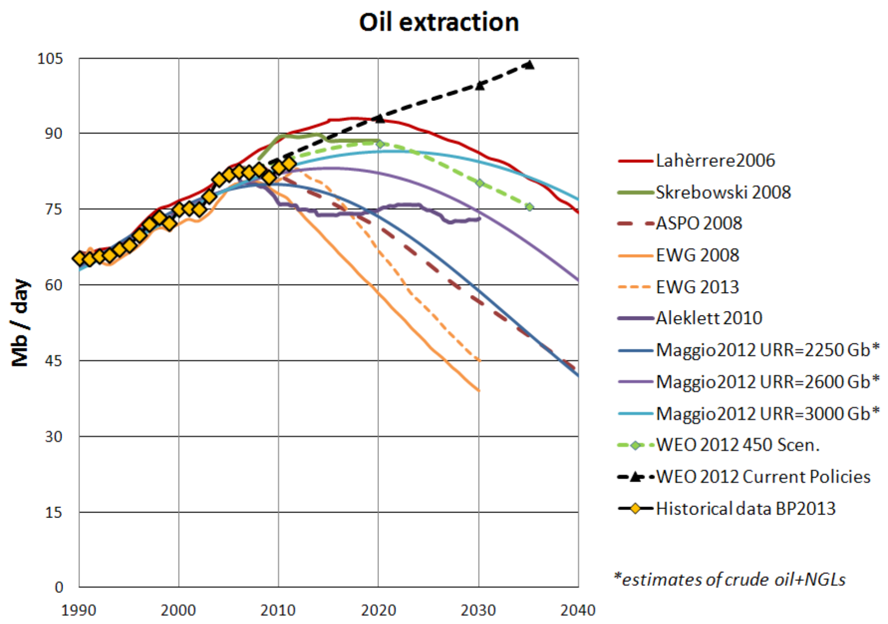


Figure 3: Estimations of oil extraction by different authors. There is a lack of standardization in the literature. For each study, "oil" refers to only crude oil (including NGLs) (Maggio and Cacciola, 2012); crude and unconventional (ASPO, 2009; EWG, 2013, 2008); crude, unconventional and refinery gains (Aleklett et al., 2010; Skrebowski, 2010; WEO, 2012); crude oil, unconventional, refinery gains and biofuels (Laherrère, 2006); finally (BP, 2013) historical data include crude oil, shale oil, oil sands. (Aleklett et al., 2010) adjust the total volume to the energy content since 1 barrel of NGL contains in reality 70% of the energy of an oil barrel.

Natural gas

[4] In this paper we consider the category "unconventional oil" that includes: heavy and extra-heavy oil, natural bitumen (oil sand and tar sands) and oil shales. Biofuels, CTL, GTL and refinery gains are modeled individually.

We consider conventional and unconventional gas resources, corresponding with the IEA category "Dry natural gas" or "consumer-grade", defined: "as the natural gas which remains after: 1) the liquefiable hydrocarbon portion has been removed from the gas stream (i.e., gas after lease, field, and/or plant separation); and 2) any volumes of nonhydrocarbon gases have been removed where they occur in sufficient quantity to render the gas unmarketable".[5]

Figure 4 shows the results of collecting estimates for natural gas (ASPO, 2009; Laherrère, 2010; Maggio and Cacciola, 2012; Mohr and Evans, 2011). In the graph for natural gas, it seems that ASPO's estimate is surpassed by historical data of production (probably due to it not being updated in recent years). Mohr and Evans 2011 offers a wide range between "low case" and "best guess", while we have ruled out their "high case" as it is exaggeratedly higher than the other forecasts. Laherrère's estimate falls between Mohr's two cases. We are going to take Laherrère's estimate as the most appropriate, ruling out the ASPO 2009 estimate and considering an average between Mohr's two cases.

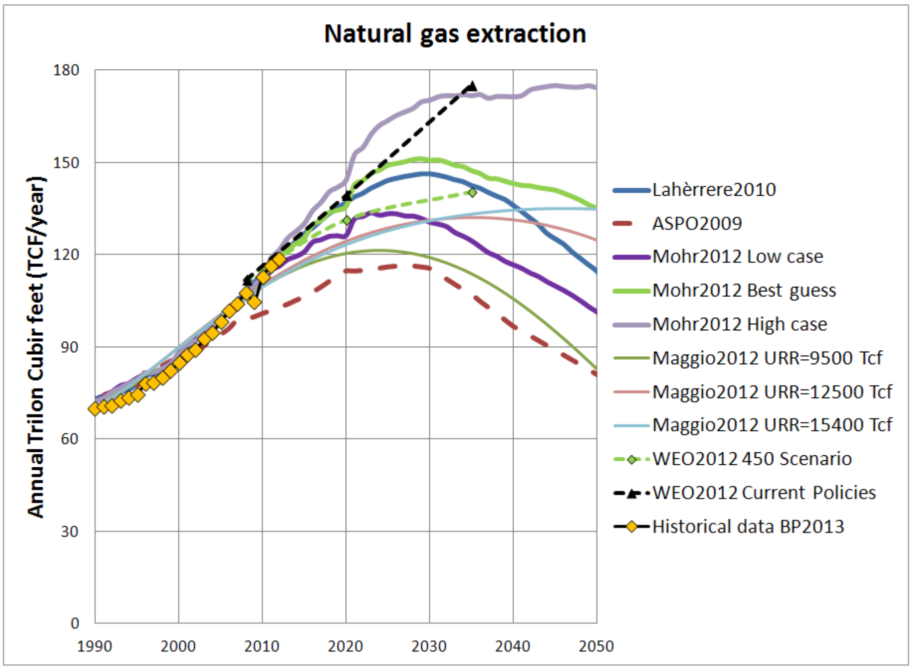


Figure 4: Estimations of conventional and unconventional natural gas extraction by different authors

Volume to energy conversion factor for natural gas

Gas reserves are usually reported in volume units (e.g. tcf[6]). However, and similarly to the situation with oil, different agencies apply different energy equivalence attending to different composition of the gas, etc.

	Original conversion given	1 bcf in Mtoe
(ASPO, 2009)	1 bcf = 166000 bcf	44.2
(EIA US, 2014, chap. Appendix G)	1.022 Btu = 1 cf	38.8
(BP, 2013)*	324.6 bcf = 3033.5 Mtoe	39.1
(IEA, 2013)	3435 tcm = 2753.7	44.1
(Mohr and Evans, 2011)	133 tcf = 140 EJ	39.8

Table 1: Equivalence between volume and energy applied by different agencias and authors. *Equivalence used by (de Castro, 2009).

In this model we have adopted the equivalence from the *US Energy Information Administration* since we used their data to estimate the regressions from the sectoral energy demand (cf. **section 3.2**). We note that it is in the low range of bcf/Mtoe, i.e. it is in the optimistic range of useful energy per volume extracted.

[5] < www.eia.gov/tools/glossary/ >
[6] tcf: trillon cubic feet, that equals 10^3 bcf (1e9 cf).

Coal

Figure 5 shows the different estimates for coal production that have been collected from the literature (EWG, 2007; Höök et al., 2010; Maggio and Cacciola, 2012; Mohr and Evans, 2009; Mohr, 2012; Patzek and Croft, 2010). We took the coal estimation of Mohr and Evans 2009 "high case" because their work takes into account the nature of coal as a mined resource better than other studies. Other studies (EWG, 2007; Höök et al., 2010; Maggio and Cacciola, 2012; Patzek and Croft, 2010) are based on logistic curves similar to the ones used for oil. The liquid nature of oil makes fast extraction in mature fields impossible, no matter how much infrastructure is used. Coal is a mineral and, therefore, more infrastructure and extraction effort can replace the low quality of the resource. If the maximum extraction is higher, this means that, with the same amount of resource, the curve goes up more and then goes to zero faster. The curve that best fits this is the one we choose: the "Mohr2012 high case". In addition, we choose this curve because the historical data seem to support our argument: we have already passed the maximum production that some studies established (EWG, 2007)and (Mohr and Evans, 2009) best guess).

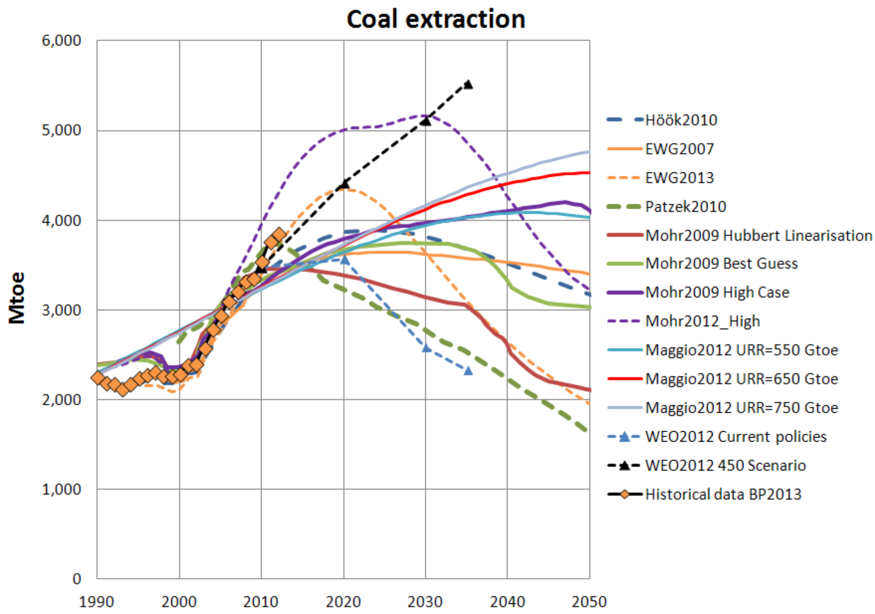


Figure 5: Estimations of coal extraction by different authors. (1 Mt = 0.482 Mtoe (Höök et al., 2010)).

Since different types of coal exist with different thermal equivalente (e.g. lignite, hard coal, etc.), we take the average value of the last 30 years as reported by (BP, 2013): 1Mt = 0,4844 Mtoe, as done by other studies (e.g.(Höök et al., 2010)).

Uranium

Finally, Figure 6 shows the uranium production curve that we have taken into consideration, which is the update of the only study on uranium to be found in the literature (Zittel, 2012). We do not believe that the technologies that claim they could increase the fisible material by 50 to 100 times, like fast breeders and the so-called fourth generation reactors, will be available during the next decades (Cellier, 2009). Therefore, they are not taken into account in this model. We also assume in our model that there are enough reactors to use all the available uranium, which may be a bit optimistic, since (Deutch et al., 2009; Schneider et al., 2012, 2009) conclude that the current trend of the buildup of new reactors is too low to even maintain present nuclear activity.

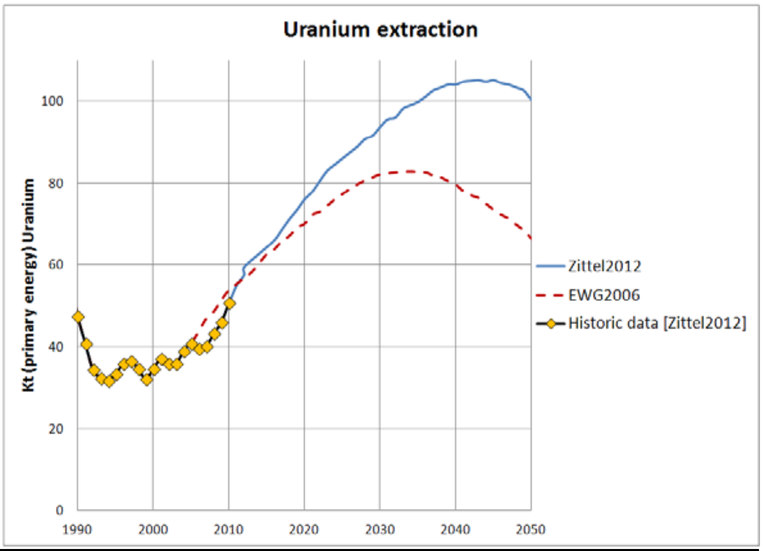


Figure 6: Estimations of uranium extraction by different authors.

Resource		Reference	Description	URR	
Oil	Conv.	(Maggio and Cacciola, 2012) middle scenario.	Hubbert method.	2,600 Gb	14.5 ZJ
	Unconv.	*Best Guess:* Own projection based on (de Castro et al., 2009)	Extrapolation of past trends deployment (+ 4.5 %/yr)	750 Gb	4.2 ZJ
		High case: (Grushevenko and Grushevenko, 2012)	High deployment rate (+ 6.6 %/yr)		
Natural gas		*Best Guess*: (Laherrère, 2010) Best Guess	Hubbert method: "creaming curve".	13,000 tcf	13.6 ZJ
		High Case: Best Guess from (Mohr, 2012)	12,900 tcf of conventional + 7,200 tcf of unconventional.	19,100 tcf	19.9 ZJ
Coal		(Mohr, 2012)	High Case, static. Mining model extraction.	670 Gtoe	27.8 ZJ
Uranium		(Zittel, 2012)	Hubbert method, considering RAR (<260 $/KgU) and IR of NEA.[a]	19,500 KtU	8.2 ZJ

Table 2: Non-renewable resources used in the model.

[a]RAR: reasonably assured resources; IR: Inferred resources; NEA: Nuclear Energy Association.

For comparison, the meta-analysis of non-renewable energy resource estimates performed by (Dale, 2012) that review over 300 studies obtained the following URR values as medians: 13.2 ZJ (conventional oil), 10.5 ZJ (conventional gas) and 24.8 ZJ (coal). Thus, we are assuming values in the upper range of the literature. The studies that focus on non-conventional resources are much less abundant and (Dale, 2012) did not report statistical results.

Other liquids: CTL and GTL

CTL (*Coal-to-Liquids*) and GTL (*Gas-to-liquids*) refer to the transformation of coal and gas into liquid hydrocarbons. Different technologies exist,[7] mostly based on Fisher-Tropsch process. However, all are characterized by low efficiencies: GTL conversion technologies are around 55% efficient and coal conversion between 27-50% (Greene, 1999; Höök and Aleklett, 2010; IPCC, 2007b). Their current production is exiguous: less than 0,3 Mb/d in 2011 (WEO, 2012). Usually growth projections from international agencies are relatively modest (e.g. +11%/yr for GTL in the *New Policies Scenario* of (WEO, 2012)), due to their high cost and the common assumption that no oil restrictions will exist in the scope of their projections. Thus, when interpreting the scenarios, we will assume higher development growth due to the liquid scarcity in our model.

[7] It can be achieved through either coal gasification into syngas (a mixture of hydrogen and carbon monoxide), combined using the Fischer-Tropsch or methanol-to-gasoline synthesis process to produce liquid fuels, or through the less developed direct-coal liquefaction technologies in which coal is directly reacted with hydrogen (WEO, 2012).

CTL faces compelling challenges that limit its potential to significantly deploy at world level: very high capital costs (many authors state that financing CTL projects can be difficult unless public incentives and subsidies are provided), a very low efficiency, the assumption that there would be large amounts of coal available and significant environmental impacts (Höök et al., 2013). In fact, the works published in the last five years highlight a considerable reduction in planned CTL plant capacity, as pointed out by (Höök et al., 2013; WEO, 2012). Moreoever, any new CTL plant that would be planned to be built outside of South Africa (only country where the technology can be considered as mature) may behave more like an early mover (i.e. the cost penalty was estimated in more than a 50% (Williams et al., 2009)).

There are many ways to liquefy natural gas, and several pilot plants, trial projects and research initiatives exist. However, only two companies – Sasol and Shell – have built large scale commercial plants (>5,000 b/d capacity). The GTL industry is essentially immature and many important patents are held by relatively few companies (Wood et al., 2012). Unlike CTL plants, the construction and operation of large scale GTL plants is now a reality, with increasing momentum. After the experiences of Sasol's Mossgas GTL plant in South Africa and Shell's Bintulu plant in Malaysia the first decade of the 21st century has witnessed the construction and start of the Oryx 34,000 b/d GTL plant and the Pearl 140,000 b/d plant, both in Qatar. Moreover, a 34,000 b/d GTL plant is being built in the Escravos region in Nigeria and is expected to become fully operational in 2013. From 2001, the average global growth trend has been around +21% per year.

We decided to adopt a simple modeling approach following the logic of the model. While the liquids supply is able to cover the demand, these technologies grow following past trends. However, when the supply is "close"[8] to be unable to cover it, a crash program is automatically activated in all scenarios that significantly increase the production from both GTL and CTL. However, the modeling is different attending to their different current situations: while GTL is assumed to be able to automatically increase its deployment level, CTL will face significant barriers in the first stages. (Höök et al., 2013) report typical construction times of 4 to 5 years. For example, the worldwide crash coal liquefaction program modeled by (Hirsch et al., 2005) assumes that the first coal liquefaction plant in would begin operation four years after a decision to proceed, assuming a following growth of +38% per year. However, the latter is an *ad hoc* value. In our model, we will assume no lags in the implementation of the CTL crash program but setting its annual growth to 15-20% (similar to current GTL deployment growth) since higher values seem very improbably in the light of the current constraints of the technology and the proximity of the divergences between supply and demand in the liquids sector that activate in practice the crash programs in the model. In terms of efficiency, we assume that the CTL process will start at current levels (27%, (Höök and Aleklett, 2010)), and since 2020 will grow linearly until reaching 45% in 2050.

3.1.2. Integration of resource curves

To be able to use these data in our model we must transform them, since it is a dynamic model that considers demand. Production depends on it: if the world economy goes into crisis and does not demand gas, for example, it will not be produced. The maximum energy resource extraction curves as a function of time have been transformed into maximum production curves as a function of resources. Production will therefore be the minimum between the actual demand and the achievable maximum production.

In these curves, as long as the resources are large, extraction will not be limited physically and we make it equal to the total maximum production. When the resources diminish, physical limits start to appear and production is reduced. In this way, the model uses a stock of resources (based on the URR taken by each author) and it studies how this stock is emptied depending on production, which is in turn determined by demand and maximum extraction. Figure 7 gives a hypothetical example of the dynamic model used and a production curve.

[8] When the parameter abundance goes below 0 (see section 5).

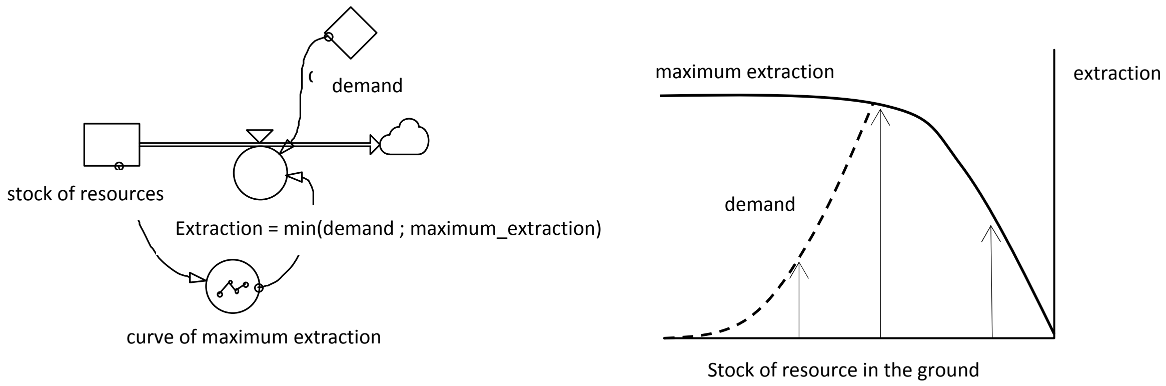


Figure 7 (Mediavilla et al., 2013): Maximum extraction curves as a function of resources. Left: the systems dynamics model used to model extraction. Right: a curve of maximum extraction (solid) compared with the demand (dashed). Both curves meet when the peak of the resource is reached.

Figure 8 shows the maximum extraction curve used in the model for all the non-renewable fuels in EJ. The x-axis represents the stock of non-renewable energy available, according to the estimated resources of fossil and nuclear fuels. The y-axis represents the maximum extraction of this energy that could be obtained depending on the stock of the resource still unexploited. As can be seen, when the resources diminish, the maximum extraction decreases until it reaches zero, when the resource is exhausted.

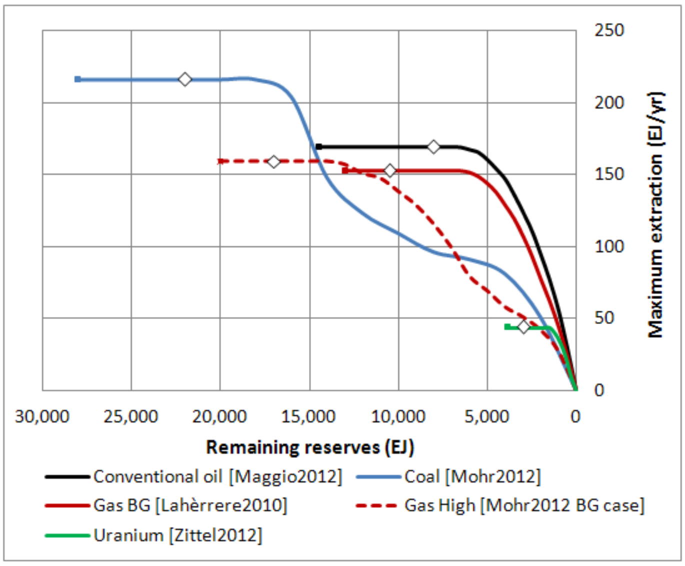


Figure 8: Curves of maximum extraction in function of the remaining reserves for all the non-renewable resources (Primary Energy). The y axis represents the maximum achievable extraction rate (EJ per year) associated to the remaining reserves (EJ). For each resource, the extreme left point (that coincides with the maximum value of reserves) represents its URR. Thus, as extraction increases and the remaining reserves fall below the point the maximum extraction can be achieved, the extraction is forced to decline following the estimations of the studies selected. We also show by a rhombus the 2007 level of remaining reserves for each resource.

3.1.3. Renewable resources modeling

Renewable energy is usually considered as a huge abundant source of energy; therefore, the technological limits are assumed to be unreachable for decades, and the concern is on the economic, political or ecological constraints imposed (de Castro et al., 2011; IPCC, 2011). However, several important constraints limit their practical availability. In this section we discuss the techno-ecological potential of renewable energies considered in the analysis.

Bioenergy

Bioenergy provides approximately 10% of global primary energy supply and is produced from a set of sources (dedicated crops, residues and Municipal Solid Waste (MSW), etc.) that can serve different uses (biofuels, heat, electricity, etc.). For the sake of simplicity, we decided to divide it into 3 categories for differentiated uses:

1- Traditional biomass (1st generation): It is the biomass used by large populations in poor-countries ((WEO, 2010) estimates for 2008 that 2.5e9 were using 724 Mtoe). We asume a reduction in the number of persons dependant on traditional biomass from 36% of global population in 2008 to 25% in 2035 (WEO, 2010). Due the increase of population, this reduction is not so important in absolute terms.

2- Residues (3rd generation). Including agricultural, forestry and MSW. Currently, only MSW exists at commercial level. The 3rd generation biofuels (cellulosic) are still in R&D and doesn't appear in the model until 2025 (Janda et al., 2012). This category will be apply to thermic uses, as it happens lo a large extent currently (IPCC, 2007b, 2007c).

3- Dedicated crops (2nd (current bioethanol and biodiesel mainly) and 3rd generation). The 3rd generation is simply modeled as an improvement of +15% in the power density (as estimated by (WBGU, 2008)). We assume these will be mainly used for biofuel production since it currently happens and as previous work estimates the substitution urgency will be on oil liquids (e.g. (Mediavilla et al., 2013)).

4th generation (algae) is not considered due to the high uncertainties of the technology and the long-term of its eventual commercial appearance (Janda et al., 2012).

The techno-ecological potential estimation of these categories is a sensitive and difficult task. The foreseeable growth of land for food for the next few decades (due to population and affluence growth) is projected to be 200–750 MHa (Balmford et al., 2005; Bruinsma, 2003; Rockström et al., 2007; Schade and Pimentel, 2010), while the projected growth of new infrastructures because of population and affluence growth is more than 100 MHa. Moreover, it is estimated that current and future crop yields will be affected negatively by climate change (IPCC, 2014a), offsetting potential productivity gains from technological innovation. According to (FAOSTAT, 2014), there were 1526 MHa of arable land and permanent crops in 2011. In view of the current situation, in which almost 15% of the world population is undernourished (FAO, 2012), a very large surface for bioenergy at global level is not compatible with future scenarios as the ones explored in this paper.

Although currently there is a worldwide rush for land, (around 1.7% of agricultural area has been reported to have been bought or rented for long periods of time since the year 2000 (Anseeuw et al., 2012))

Thus, we will distinguish between 2 kinds of land, in relation to the inferred land competition: first, we will consider a potential in marginal lands that will not imply a competition with current crops such as proposed by (Field et al., 2008); and secondly a potential in current cultivated areas that will be set for each scenario in function of the assumed pressure. Related to the gross power density of 2nd generation biofuels under land competition, we will consider as reference the world average value given by (UNEP, 2009) based on real data (36 Mha occupied for 1,75 EJ) that estimates at 0,155 W/m2 (although following a conservative methodology – further discussed in (de Castro et al., 2013a)).

		Reference	Surface	Gross power density	Potential
			MHa	W/m2	EJ/yr
2nd generation	Marginal lands	(Field et al., 2008)	386	0.033[a]	4.1 (gross power)
	World average	(de Castro et al., 2013a)	100 (standard scenario)	0.155[b]	4.9 (gross power)
3rd generation (from 2025)	Dedicated crops	(WBGU, 2008)	0	0.18	+2.3 (gross power)
	Agriculture & Forestry residues	Own estimation	-	-	25 (NPP)

Table 3: Bioenergy power density and potentials assumed for each resource. Other potential resources, such as 4th generation biomass (algae), are not considered due to the high uncertainties of the technology and the long-term nature of its eventual commercial appearance (Janda et al., 2012).

NPP: Net Primary Production.

[a] (Field et al., 2008) find that 27 EJ of NPP can be extracted from 386 Mha of marginal lands. A transformation efficiency to biofuels of 15% is assumed.

[b] The gross power density for the best quality lands was estimated at 0.3-0.36 W/m2 in Brazil (de Castro et al., 2013a).

There is currently a controversial debate about the potential of the valuation of agricultural and forestry residues, because of its threat to soil fertility preservation in the long run, biodiversity conservation and ecosystem services (Gomiero et al., 2010; Wilhelm et al., 2007). Thus, in order to remain conservative, we halve the estimation of (WBGU, 2008) to 25 EJ Net Primary Production (NPP).

We assume in this document (Table 3) 100 MHa for the land occupation of 2nd generation biofuels. This value may change when interpretation different scenarios: for example (Doornbosch, 2007) estimates in 440 MHa the additional land potentially available (mainly in Latin America and Africa). However and as reference, since 2000 the area from south countries that has been bought or long-term rented by trasnationals and investment funds has been estimated in more than 80 MHa (Anseeuw et al., 2012).

The Forrester diagram of the modeling is shown in the **Figure 9**.

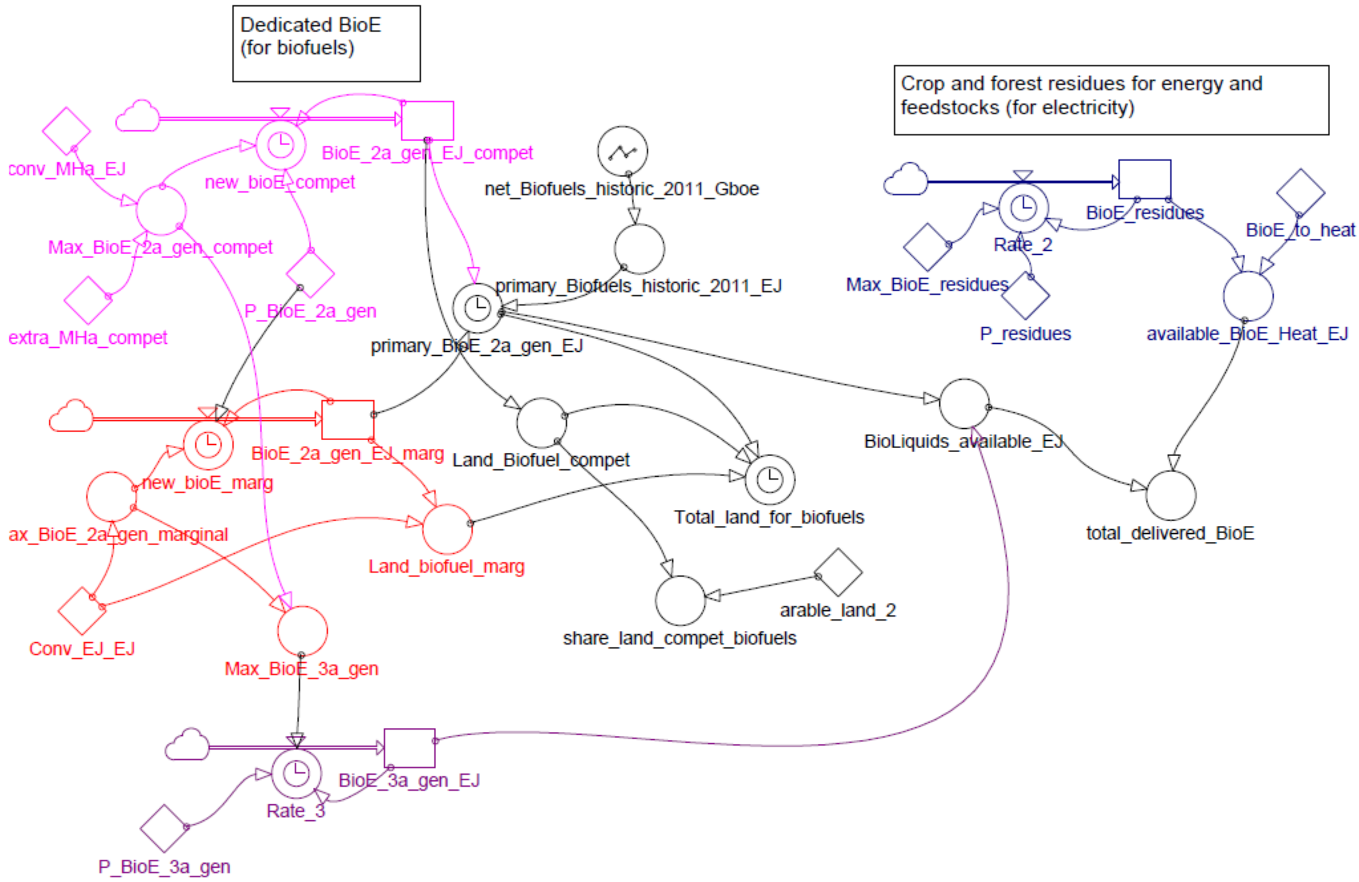


Figure 9: Forrester diagram of the modeling of the bioenergy in the WoLiM model.

Electrical generation from renewable resources

The most promising electric renewable energies are solar and wind (Smil, 2010). However, recent assessments using a top-down methodology that takes into account real present and foreseeable future efficiencies and surface occupation of technologies find that the potential of their deployment is greatly limited by technical and sustainable limits (de Castro et al., 2013b, 2011). Thus, the evaluation of the global technological wind power potential, acknowledging energy conservation, leads to a potential of 30 EJ/yr (de Castro et al., 2011). While the calculus of the real and future density power of solar infrastructures (4-10 times lower than most published studies) leads to a potential of 60-120 EJ/yr (de Castro et al., 2013b) in approximately 60-120 MHa.

Sea waves on coasts and tidal resources are limited to a physical dissipation of 3TW, hydroelectricity is limited by a total gravitational power of rain of 25 TW, geothermal renewable resources are limited by a total Earth dissipation of 32 TW (Hermann, 2006), and biomass is limited by a total terrestrial net primary productivity of roughly 60TW (humans already appropriate indirectly 20-50% in an unsustainable way (Cramer et al., 1999; Haberl et al., 2007; Smil, 2008; Vitousek et al., 1986). Acknowledging the high dispersion of these resources and their role to the energetic and material fluxes of ecosystems, we will estimate in this paper than less than 1 TWe could be attained in a sustainable way by renewable energies other than solar and wind.

Table 4 summarizes the renewable energy techno-ecological potentials, investment costs and lifetimes assumed:

	Techno-ecological potential	Investment cost			Lifetime
References	(de Castro, 2012; de Castro et al., 2013b, 2011)	(Teske et al., 2011)			Conventional values
Technology/Unit	TWe	2011$/We			years
		2010	2030	2050	
Hydroelectrical	0.5	4.8	6.3	6.9	100
Wind[a]	1	8.3	6.6	6	25
Solar	3	26.9	7.4	7.4[b]	25
Waste & MSW	0.3	3.9	3.3	3.2	40
Geothermal	0.2	15.9	9.3	6.6	40
Oceanic	0.05	9.2	2.8	2.1	25
TOTAL	5.05				

Table 4: Data of electric renewable in the model. "TWe" represents power electric production: TWh/8760.

***The learning curve for wind is adapted from (Teske et al., 2011) in order to aggregate both onshore and offshore wind.**

[b] The solar investment cost is maintained constant after 2030 since we judge it to be too optimistic that the solar technologies will manage to be less expensive than wind. In fact, in recent years, the price of solar modules has fallen significantly due to efficiency improvements but also to dumping and excess capacity effects in the crisis.

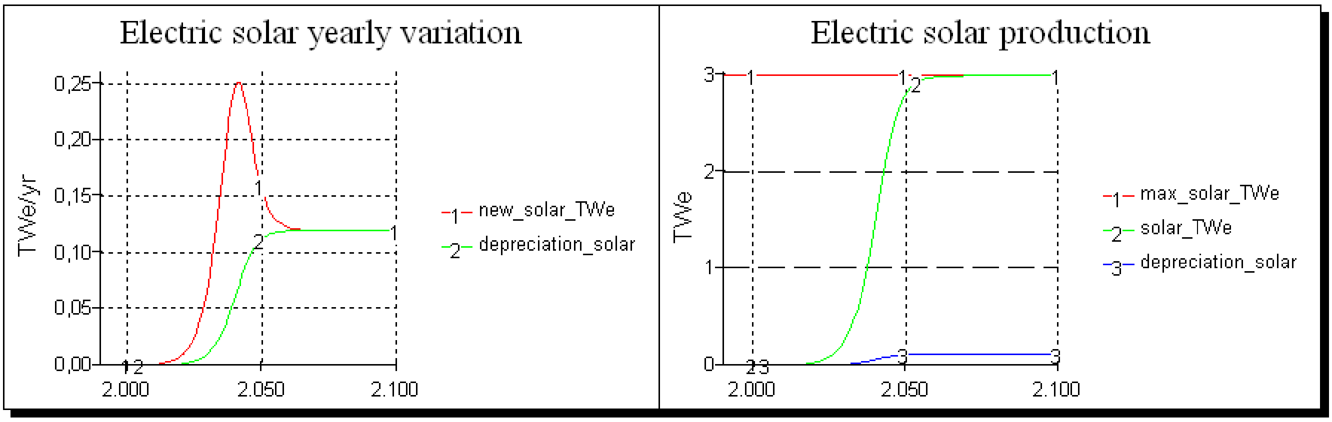
Below we represent the equations and Forrester diagram (**Figure 11**) of solar electric generation; all electric renewables are represented by analogue structures. **P1_solar** represents the annual growth considered in each scenario (**past_solar** represents the past trends). However, this growth is adjusted to a function that introduces diminishing returns on the new solar power (**new_solar_TWe**) depending on the proximity to the potential (**max_solar_TWe**) reducing the exogenous growth initially set (Höök et al., 2011), as shown by **equation equation** (1**)**:

$$New\_solar(t) = replacement\_solar + P1\_solar(t) * solar\_Twe(t-1) * (max\_solar\_TWe - solar\_Twe(t-1))/(max\_solar\_TWe)$$ equation (1)

Replacement_solar just compensates the depreciation rate. **Solar_TWe** accounts for the level of solar power accumulated, balanced between the new power installed (in new locations or also due to the replacements of depreciated structures (**depreciation_solar**)):

$$\frac{d(solar_{TWe})}{dt} = \text{new\_solar\_TWe} - \text{depreciation\_solar}$$ equation (2)

In the **Figure 10** we represent the dynamics of the **equation (2)** with an example to illustrate the behavior of exponential growth constrained by an exogenous limit.



a) b)

Figure 10: a) New solar electric production and depreciation by year (TWe/yr); b) Total electric solar production (TWe). In this figure we represent the dynamics of equation 1 considering a very rapid growth of solar (+30%, as in scenarios 2 and 4). While being far from the potential limit, exponential growth drives the growth of new solar power. As the total solar power installed increases, the depreciation of infrastructures becomes significant. Finally, just 10 years after reaching the maximum installation rate, 95% of the potential is achieved in2052.

We account for the electrical production (**solar_production_TWh**), the land occupied (**surface_MHa_solar**) and the investment needed (**invest_solar_Tdolar**):

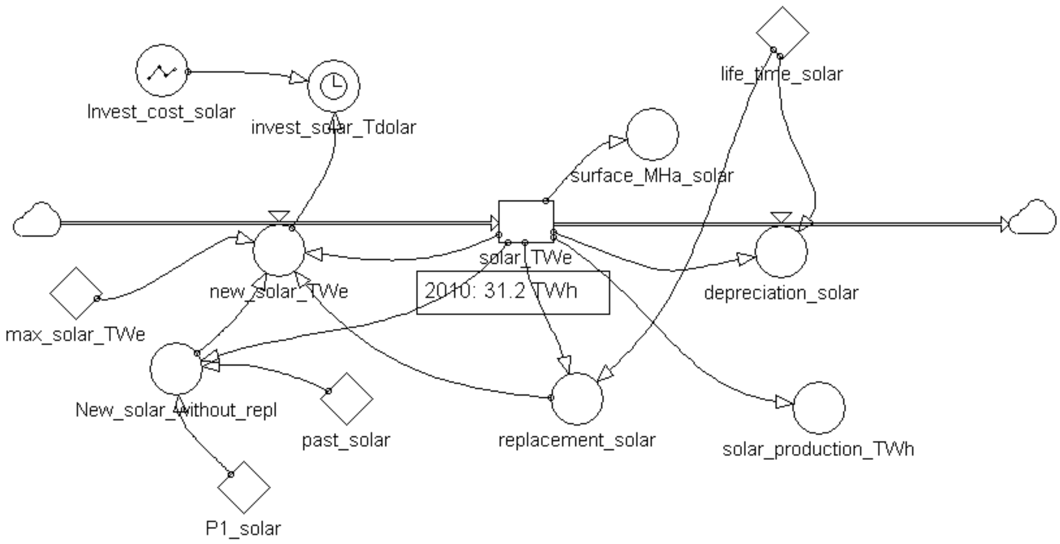


Figure 11: Structure of the renewable electric technologies. Here, we represent solar.

We compute the investment for building new plants and to replace or re-power the already existing ones following (Teske et al., 2011). We assign the same cost to both structures, although it seems obvious that the costs when replacing should be inferior, in order to be sure not to underestimate that cost. Moreover, other costs are also computed: grid development (renewable energies are often located in remote areas) and balancing costs (increase of operating costs).[9]

Grid reinforcement costs are, by nature, dependent on the existing grid. We use the median value calculated in (Mills et al., 2012) for 40 transmission studies for wind energy in the USA, which is, in fact, on the upper side of the comprehensive study made by (Holttinen et al., 2011): 300 $ 2011US/KW of wind installed. Other costs, such as balancing costs, are also introduced into the model: (Holttinen et al., 2011) also concludes that at wind penetrations

[9] Increase in reserve requirement is not computed since the power and cost of non renewable electricity production are not explicitly modeled.

of up to 20% of gross demand (energy), the system operating cost increases arising from wind variability and uncertainty amounted to about 1–4 €/MWh of wind power produced. We assume here similar costs for the combined variable renewable producers -solar and wind- (see Table 5), extrapolating the cost until it reaches a maximum of 5 euros/MWh at 50% of total electricity share. This cost is assigned to the wind production, assuming that solar technologies might have more capacity to store energy in the future (e.g. CSP with thermal storage).

Combined variable renewable production share	Balancing cost [$ 2011US/MWh produced]
10 %	2.8
20 %	4.2
30 %	5.6
50 %	7
> 50 %	7

Table 5: Integration cost adapted from (Holttinen et al., 2011).

The thermal renewable in Industrial and Buildings sectors is discussed in **section 3.3**.

3.2. Energy demand estimation

A diversity of techniques can be used for estimating the energy demand for an economy or sector. Since the model is highly aggregated, we applied the Energy Intensity method, that has already been used in similar studies (Furtado and Suslick, 1993; Saddler et al., 2007). This model is simplistic from the economic point of view because it does not explicitly include either the price or the economical structure. However, when medium and long-term projections are made, it is possible to consider that energy demand and its main drivers (GDP and technological improvement) dominate over the variations of fuel prices and its substitutes (de Castro, 2009; Furtado and Suslick, 1993; Saddler et al., 2007). In fact, prices and costs can falsely signal decreasing scarcity. (Reynolds, 1999) demonstrate that, when considering the size of the resource base as unknown (or ignored), it is possible to have several years of increasing production simultaneously with lower prices and costs until a sudden, intense price rise occurs with a huge cut in production, similar to the oil shock in 2007-08 (Hamilton, 2009). Another attractive feature is the fact that, while energy and GDP per capita vary by more than one order of magnitude as one goes from developing to developed countries, the intensity does not change by more than a factor of 2, indicating that there are important commonalities among the energy systems of rather different countries (Goldemberg, 1996).[10]

Considering the sectoral Energy Intensity as energy used by a sector divided by the total GDP of the economy (equation 3), this method can be summarized as follows:

1- Estimation of the future evolution of GDP (set exogenously depending on the scenario),
2- Estimation of the evolution of the Energy intensity for each sector (calculated in this study by econometrics),
3- Finally, multiplying the GDP by the Energy intensity of each sector (I_i), the Energy Demand for that sector (E_i) is obtained dynamically, see **equation (3)** below:

$$E_i = GDP \cdot I_i \qquad \text{equation (3)}$$

[10] The use of a world aggregated indicator also allows outsourcing and carbon-leakage issues that may be significant at national level (e.g. (Baksi and Green, 2007)) to be avoided.

Index *i* refers to the 3 economic sectors considered: Transport, Electric and IB (Industrial and Buildings) sectors.

A conventional way for characterizing the evolution of energy intensity is shown in **equation (4)** (Schenk and Moll, 2007), which can also be written as in equation 5, where annual Intensity (I_t) decreases each year at a constant rate (a=1-AIE) in relation to the previous year (I_{t-1}):

$$I_t = I_{t=0} \cdot (1 - AEI)^t \qquad \text{equation (4)}$$

$$I_t = I_{t=0} \cdot (1 - AEI)^t = (1 - AEI) \cdot I_{t-1} = a \cdot I_{t-1} \qquad \text{equation (5)}$$

AEI represents the Annual Efficiency Improvements.

Thus, the parameter "a" or (1-AEI) accounts for technological change, and by varying it, it is possible to explore different scenarios of sectoral technology-efficiency improvements.

The results of the sectoral energy intensity regressions are shown in Table 6 and Figure 12. Appendix B depicts the results of the statistics tests to validate the models.

Energy sector	**Sectoral Energy Intensities**		**Period**
Total PE demand	${I^{tot}}_t = 0.988582 \cdot {I^{tot}}_{t-1}$ (R^2=0.999840)	EJ / US$	1971-2010 (regression)
Transport PE demand	${I^{transp}}_t = 0.993298 \cdot {I^{transp}}_{t-1}$ (R^2=0.999841)	EJ / US$	1971-2007 (regression)
Electricity generation	${I^{elec}}_t = 1.00127 \cdot {I^{elec}}_{t-1}$ (R^2=0.999916)	TWh/ US$	1980-2010 (regression)
IB PE demand	${I^{IB}}_t = 0.995 \cdot {I^{IB}}_{t-1}$	EJ / US$	1990-2010 (calibration)

Table 6: Results of the sectoral energy intensity regressions for Total, Transport, and Electricity generation; and of the calibration for the IB sector. All dollars in the paper are in 2011 US$. PE: Primary Energy. We have used the (World Bank database, 2014) for the historical series of world GDP at constant prices in US2011 T$ and Total Primary Energy (PE) demand, (IEA ETP, 2010) Transportation PE use and (US EIA db, 2014) for the electrical generation. IB PE intensity was calculated internally in the model for the calibration period (1990-2010) as the subtraction of Total energy minus Transport and Electrical sector (generation and losses).

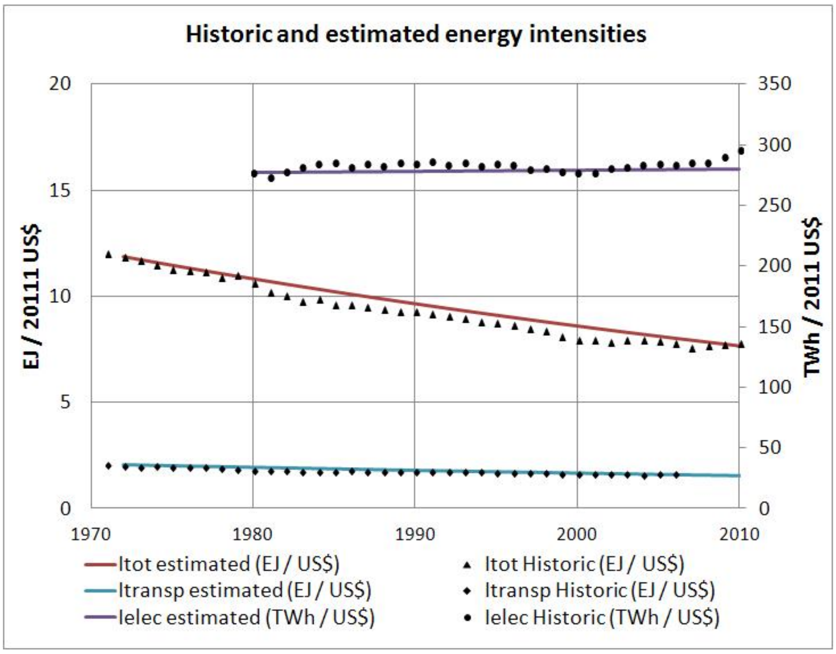


Figure 12: Historic and estimated energy intensities by sectors. Itot refers to Total Energy Primary intensity (EJ/US$), Itransp to Transportation intensity (EJ/US$), and Ielec to Electrical generation intensity (TWh/US$). All dollars in the paper are in 2011 US$.

Our results indicate that in the last 40 years, the world TP energy intensity has improved at a yearly average rate of 1.15 % ((Smil, 2005) estimated 1% improvement for the 20th century). This evolution has not been uniform, and since the year 2000 its value has remained constant at around 8 EJ / 2011 US$. As signaled and studied by (Baksi and Green, 2007), an important question for future scenarios is whether a 1% rate of decline in the global average annual energy intensity can be improved upon over the course of the 21st century. Or, alternatively, if it will become more difficult to maintain a 1% rate of decline, as the best improvements in energy efficiency, and the largest gains from sectoral output shifts, are ‘‘used up’’.

Transport and Buildings primary energy intensities have also improved in the last decades, although at smaller rates (0.7% and 0.5% respectively). Finally, the electricity generation intensity has remained stable at 275 TWh/2011 US$ due to the massive transition of more developed economies to that (more efficient) source of energy (Fouquet, 2010).

Energy intensity scenario implementation

In order to account for the biophysical and thermo-dynamical limits in the substitution of inputs in production in medium and long-term scenarios (as stated by Ecological Economics, e.g. (Ayres, 2007; Ehrlich, 1989; Stern, 1997)), we modify the conventional expression of the energy intensity (**equation (5)**) as a physical indicator as proposed by (Schenk and Moll, 2007):

$$I_t = I_{min} + (I_{t=0} - I_{min}) \cdot a^t \qquad \text{equation (6)}$$

a represents indirectly the Annual Efficiency Improvements (a=1-AEI), while I_{min} is a horizontal asymptote that represents the minimum value of the energy intensity. Both values will vary depending on the scenario storyline and quantification (see **section 4**). As reference, we use the studies of (Baksi and Green, 2007; Lightfoot and Green, 2002) that analyze the potential efficiency improvements in each sector until 2100 with a methodology that helps to eliminate future energy intensity decline scenarios involving implausible values. A practical application for illustrating its behavior is done in the next paragraph.

Application of the Energy Intensity as physical indicator

When applying energy intensity scenarios two hypotheses are assumed. At a world level, only regional convergence has been found, mainly among OECD members (e.g. (Liddle, 2010)). Also, due to the different development levels, efficiency margins that can be achieved vary for different countries. Due to the world-aggregation of the model, we decided to take maximum values of efficiencies, assuming that all countries would be able to reach these values (following a similar methodology to (Baksi and Green, 2007; Lightfoot and Green, 2002)). Thus, we consider this optimistic hypothesis so as to be sure not to minimize efficiency and potential technological improvements.

In order to illustrate the behavior of the Energy Intensity as physical indicator, we represent 4 future evolutions of the total energy intensity. 1 and 2 use the conventional formula (see equation 5), while 3 and 4 use the modified version (equation 6). (Baksi and Green, 2007) demonstrated that, even when large efficiency improvements are applied, physical and thermodynamic constraints appear and the yearly reduction rate of energy intensity is limited. We compare a reference scenario (-1.15% yearly decrease and horizontal asymptote at 25% from current level) with their most optimistic scenario (which they judge as unrealistic) of yearly improvements of 2% and a horizontal asymptote at 10.8% from current level. We also introduce the (WEO, 2012) projections for comparison:

- "1. Conv. a_hist": conventional equation and extrapolation of past trends (-1.15% yearly).
- "2. Conv. a_max": conventional equation and -2% yearly improvements.
- "3. Schenk a_hist": extrapolation of past trends (-1.15% yearly) and I_{min}=2.5 EJ/2011 US$ with modified equation.
- "4. Schenk a_max": -2% yearly improvement and I_{min}=1.08 EJ/2011 US$ with modified equation.

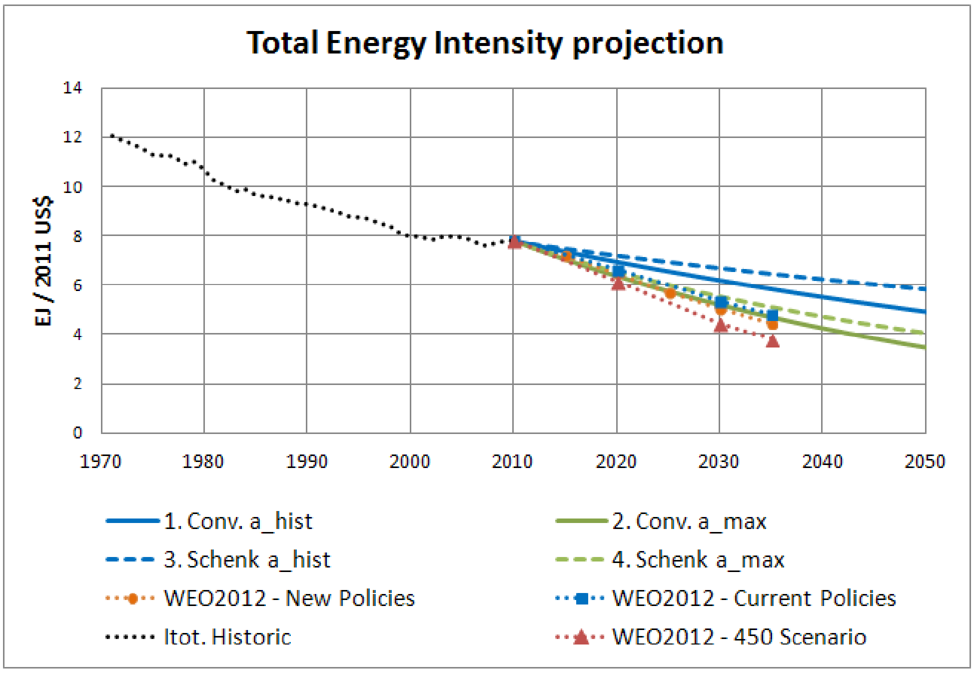


Figure 13: Application of the Energy Intensity as physical indicator.

The first observation is that (WEO, 2012) projections imply improvements in the order of (or superior to) 2% per year, i.e., doubling the historical values and outside the range of the values identified by (Baksi and Green, 2007) as being realistic and achievable (0.9-1.22%). When comparing the modified expression with the conventional, we observe that the fact of not limiting the improvements in the long-term implies significant reductions of intensity projection in 2050 for both scenarios: 1 EJ / 2011 US$ in the reference and more than 0.5 EJ / 2011 US$ in the most optimistic one.

3.3. Economic sectors modeling

We decided to model the economy as an aggregate of four main sectors: Transportation, Electricity, Industry and Buildings (an aggregate of Commercial and Residential). This level of aggregation allows thus to explore the impact of the energy transition by sector. In order to calibrate the model we used the data provided by the *International Energy Outlooks* from the *US Energy Information Administration*.

In this model version, we decided to focus in this study on the Transport and Electricity generation sectors, while maintaining a high level of aggregation in the Industrial and Building sectors, which are much more complex to model since they use all kinds of fuels and energy vectors in a great diversity of technologies. The approach will be detailed in **section 3.3.3.1**.

In Figure 14 the primary energy supply by each sector modeled in WoLiM is showed. The sectors sorted by primary energy consumption: the Electricity generation (215 EJ), Industrial (165 EJ), Transportation (101 EJ) and Buildings (50 EJ). Interestingly, the electrical losses (from both generation and distribution) account for almost as much as industrial sector with 150 EJ (28% of the total TPES). In the last years, the electricity sector showed the greatest growth. As this figure illustrates, an electrification of the society without a shift in the generation mix would inefficiently spend large amount of resources.

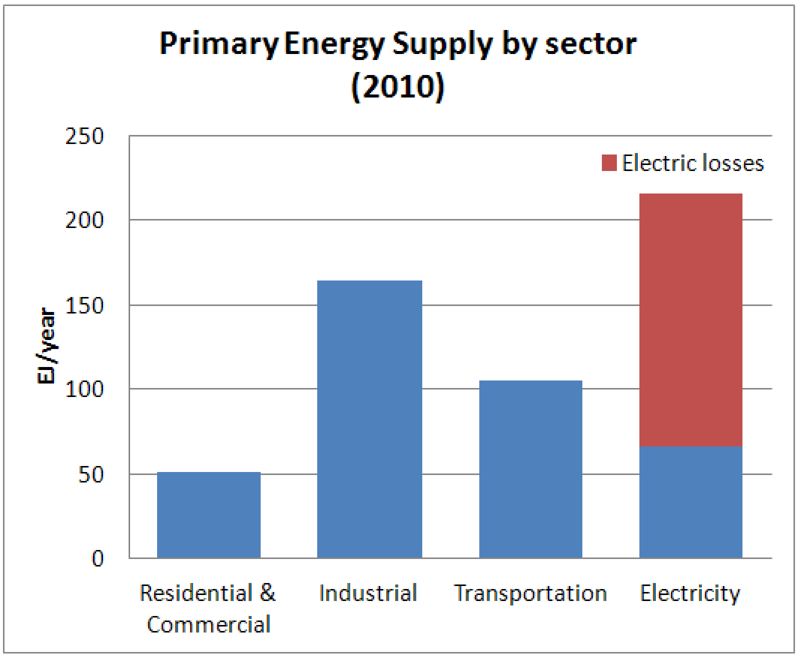


Figure 14 (IEO, 2013): Primary Energy Supply by economic sector modeled in WoLim.

Each sectoral energy demand evolution (E^i) is generated through the energy intensity method explained in **Section 3.2** and is modeled following the **equation (7)** and the **Figure 15**.

$$E^i{}_t = a^i{}_t \cdot I^i{}_{t-1} \qquad \text{i: economic sector} \qquad \text{equation (7)}$$

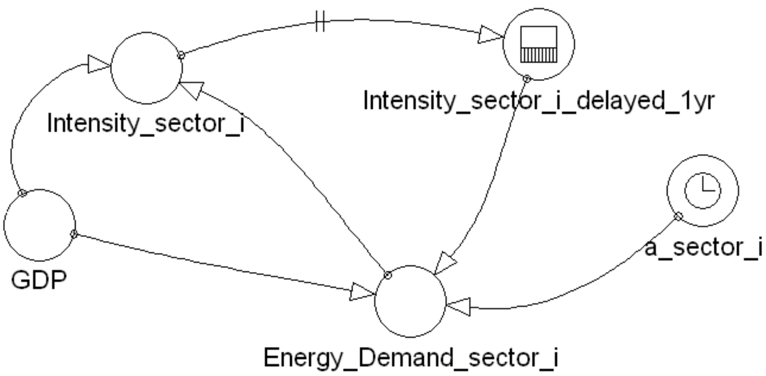


Figure 15: Forrester diagram of the energy demand modelying by sector with the energy intensity method.

In the next sections, the modeling of each sector is analyzed individually.

3.3.1. Electricity

The current generation of electricity is dominated by fossil fuels (75% in 2010 (WEO, 2012)), dominated by coal (46%) and gas (23%)). The contribution of oil is declining since the 70s and currently represents 6%. We exogenously extrapolate the past trend assuming that the oil, due to its high quality and increasing scarcity in the future, will be driven out from the electricity generation to more specific applications (see **Figure 16**).

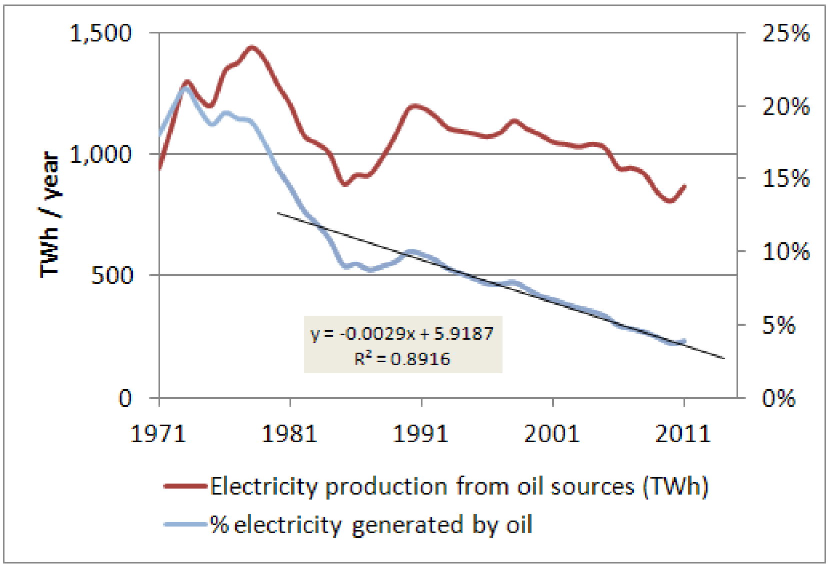


Figure 16 (own analysis from (World Bank database, 2014)): Electricity production from oil sources (TWh) and as percentage of the total electricity production.

Among the renewable energies, hydroelectricity continues to be the largest contributor due to its early historical deployment; however the new renewable energies show a strong growth in the last decade (e.g. solar +40%, wind +28%, see **Table 7**), while reaching (or close to) grid-parity costs in many locations (REN21, 2014).

	Electricity generation					
	Hydro	Wind	Solar FV	Solar CSP	Geothermal	Biomass & MSW
Ref.	(US EIA db, 2014)	(REN 21, 2012)			(WEC, 2010)	(US EIA db, 2014)
Growth	+ 2,3 %	28 %	42 %	40%	+ 4 %	+ 6,4 %
Period	1980-10	1996-11	2000-11	2006-2011	1985-2008	1990-10

Table 7: Renewable technologies for electric generation by source growth rates (yearly average).

However, still the new renewable energies reached less than 4.5% of the world electric generation in 2011 (US EIA db, 2014). In 2007, over 95% of the power generation capacity under construction worldwide was for fossil fuel and hydro power production (WEO, 2008, fig. 6.4). But the in less than a decade the trend has radically changed: the capacity additions of renewable technologies in 2013 reached the same level than for the rest of technologies (Liebreich, 2014).

In order to account for the final energy available in the form of electricity, we account for transportation losses and generation losses. In the last 30 years, transportation losses have been in the range of 8-9.5% of the total electric generation (US EIA db, 2014). Thus, we extrapolate this value for the projections.

We apply the following efficiencies to the non-renewable electricity generation:

- Nuclear: assuming a 33% conversion as by (IEA, 2013),
- Coal plants: current efficiency is estimated to be around 35%, we apply a technical improvement that would reach 40% in 2040 as assumed by (WEO, 2010).
- Natural gas: we take the usual value of 50%.

In the **Figure 17** the main structure of the Electricity sector modeling in WoLiM is displayed. The electricity demanded (**Demand_Electricity_cons_TWh**) is generated trough the energy intensity (**Ielec**). The electricity produced (**Demand_Electricity_gen_TWh**) accounts for the electricity demanded plus the distribution losses and the additional energy due to the transition to electric modes of transportation (**Increase_elec_total_TWh**). The electricity generated with renewable energies has always a priority over the other fuels. The nuclear energy evolution is a variable of the model that varies for each scenario, while the electricity share from coal and gas (oil is driven exogenously to zero as explained above, cf. **Figure 16**) are maintained constant and assumed to fulfilled the remaining demand.

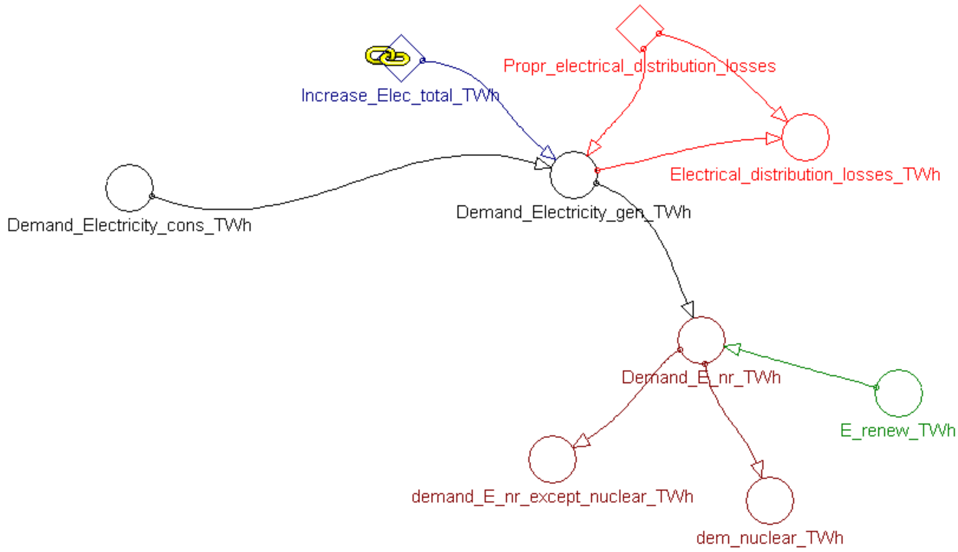


Figure 17: Forrester diagram of the structure of the Electricity sector modelying in WoLiM.

3.3.2. Transportation

Consumption in transport covers all transport activity (in mobile engines) regardless of the economic sector to which it is contributing including: road (passenger and freight), aviation, rail, marine bunkers and domestic navigation and pipeline transport. Transportation largely relies (95%) on liquid fuels; and 55% of the world total liquid fuels are dedicated to the Transportation sector.

The most immediate technological substitutes for the consumption of oil in transport are biofuels, electric and hybrid cars and natural gas vehicles (NGVs), as these are technologies that are already being utilised. Greater efficiency may also be expected, through improvements in the engines and the change to lighter vehicles. This is similar to the introduction of hybrid vehicles, as it simply represents a smaller consumption per vehicle. Cars using hydrogen, synthetic fuel and similar alternatives are not introduced in the model as they are still in a developmental stage. Other ways of saving energy, such as railways and changes in mobility patterns require more profound social transformations and costly infrastructures (and for the moment will not be included in our model).

Electric vehicles (extracts from (Mediavilla et al., 2013))

One of the most important limitations of electric cars is their low functionality, above all in terms of the capacity of accumulation of energy: 15 times less storage, according to (FTF, 2011), even taking into account the greater efficiency of electric motors and battery technology that can be expected in the next decade. Owing to this low accumulation capacity, only lighter vehicles are normally considered as candidates to be purely electrical, and even in those texts, where purely electric vehicles are considered for freight transport, such as (IEA, 2009), the goals are very low and are restricted to “light commercial and medium-duty freight-movement”. The consumption of light vehicles takes up practically half the oil used for transport (IEA, 2009). This means that around 30% of the world oil consumption can be substituted by electric (or hybrid) cars.

Despite this, electric vehicles enjoy some positive aspects. Their consumption of electricity, for example, is acceptable. If we compare the energy needs of electric vehicles with petrol vehicles of equal weight and power, (EABEV, 2008) gives a relationship of 1:3 favourable to electric vehicles (tank to wheel). According to this ratio, the necessary electricity consumption is 530 TWh for each Gb of oil that is replaced (5.71 EJ/Gb).

Another limit that should be taken into account when studying electric cars is that of the materials needed for the batteries. The most promising batteries at the moment are lithium-ion batteries, and it is thought that each electric vehicle will need between 9 and 15kg of lithium mineral per vehicle. Lithium reserves are estimated as being 4.1Mt, although some authors claim that 11Mt could be exploited (Hacker et al., 2009). (Angerer, 2009) estimates 6Mt of global reserves and, according to his data, if lithium consumption for applications unrelated with electric vehicles continues to rise at the present rate, by 2050, 2Mt of lithium will have been consumed. Assuming that this lithium will not be recycled, this would leave between 2Mt and 9Mt for electric vehicles, which could maintain a total of between 222 and 1200 million vehicles, assuming 9 kg lithium per vehicle (current fleet size is 800 million), which would be sustainable if the lithium in electric vehicles could be recycled at rates close to 100%.

This shows that a number of electric cars higher than the current number of light vehicles could be beyond the reach of this particular technology, although some 50 – 60% might be possible with serious recycling policies. Obviously, this is not an absolute limit to electric vehicles, since other types of batteries could be developed (maybe at the cost of lower efficiency), or lighter vehicles such as motorcycles could be opted for. In any case it is important to be conscious of the finite nature of valuable minerals like lithium and the need to implement strong recycling policies.

However, it should be borne in mind that electric technology finds it very difficult to replace heavy vehicles, and synthetic fuels, hydrogen vehicles or major changes in machinery and mobility will be needed in order to cover these needs.

The main reference to project the evolution of hybrid and electric vehicles in our model will follow the estimations of (EVI IEA, 2013). EVI is "a multi-government policy forum dedicated to accelerating the introduction and adoption of electric vehicles worldwide" that seeks to "facilitate the global deployment of at least 20 million passenger car EVs by 2020" (EVI IEA, 2013).

Natural Gas Vehicles (NGVs)

Differently to HEV&EV, natural gas can cover almost the whole spectrum of vehicles. Natural gas can be used in a compressed (CNG) or liquid (LNG)[11] state in several modes of transport, including road transportation, off-road, rail, marine and aviation (IEA, 2010). Generally, CNG is more commonly used for LDVs while HDVs require more energy to run and tend to use LNG to maintain an acceptable range (IEA, 2010). Despite the strong growth in the past decade (+22% per year), the total number of 16.7 million NGVs (http://www.iangv.org/current-ngv-stats/) still pales in comparison to a total worldwide number of around 1,150 million motor vehicles in 2009 (World Bank database, 2014) – i.e.1.45% of total.

CNG vehicles are currently slightly less efficient than equivalent gasoline vehicles while diesel vehicles enjoy a small net advantage. In the future, however, estimated improvements in spark ignition engines will bring all technologies much closer together (IET JRC, 2014). Thus, for the sake of simplification, we will consider that the tank-to-wheel (TTW) factors of NGVs, diesel and gasoline are equivalent.

The world gas consumption in transport is expected to increase from 20 bcm in 2010 up to 40-45 bcm in 2030 (IGU & UN ECE, 2012). Conventional economic analysis indicate that natural gas can compete with gasoline in all scenarios where gas transmission and distribution grids are present (IEA, 2010). Especially, this growth is expected to remain strongest in the regions that are also currently leading in NGV market development (Asia-Pacific and Latin America). Also, due to the foreseen liquids scarcity along the first half of the century, it seems plausible to expect a high growth in the order of the past decade (+20% per year) of NGVs in the coming years.

[11] At atmospheric pressure and temperature, natural gas has an energy content of around 40 MJ/m3 or 50 MJ/kg, as compared to gasoline (35 MJ/L) and diesel (39 MJ/L). In order to reach an acceptable range, gas needs to be stored in a way that increases the energy density. There are currently three technologies for this. The most common are CNG and LNG. CNG is gas that is compressed to a pressure of usually 200 bar, after which it is stored in cylinders. LNG is gas that has been liquefied by cooling it to below its boiling point of -163 °C (at atmospheric pressure) and subsequently stored. There are two standards for dispensing LNG: saturated LNG (8 bar and -130 °C) or cold LNG (3 bar - 150 °C) (IEA, 2010).

The NGVs in WoLiM are modeled in a similar way to the HEV&EV by an exogenous growth driven by the market penetration level assumed to be reached in the future. The development cost of retail infrastructure, that is estimated to be significant (WEO, 2012), is not modeled for the sake of simplicity. Due to the transformation processes and associated losses, the consumed gas represents 85% of the gas extracted (Kleine&NagerlVoot 2012).

Biofuels

The substitution of oil liquids by biofuels was explained in **Section 3.1.3**.

Figure 18 depicts the simplified Forrester diagram of the Transportation sector. An initial demand of energy for transport is generated through the energy intensity approach (**Dem_Transport_initial_EJ**). Subsequently, this demand is distributed by fuel shares following the historical trends. These trends are modified by the policies applied in terms of electric, hybrid and NGVs market penetration[12] as well as by the rhythms and potential of bioenergy deployment. The additional electricity required is added to the initial electricity demanded (**Increase_Elec_total_EJ**, see also the **Figure 17**). Finally, the real energy intensity of the Transportation sector is calculated after the policies (**real_Transport_intensity**).

[12] An additional condition is considered: HEV&EV and NGVs only deploy while there is not scarcity of electricity and gas, respectively. This scarcity is measured through the parameter “abundance”, as explained in **Section 5**.

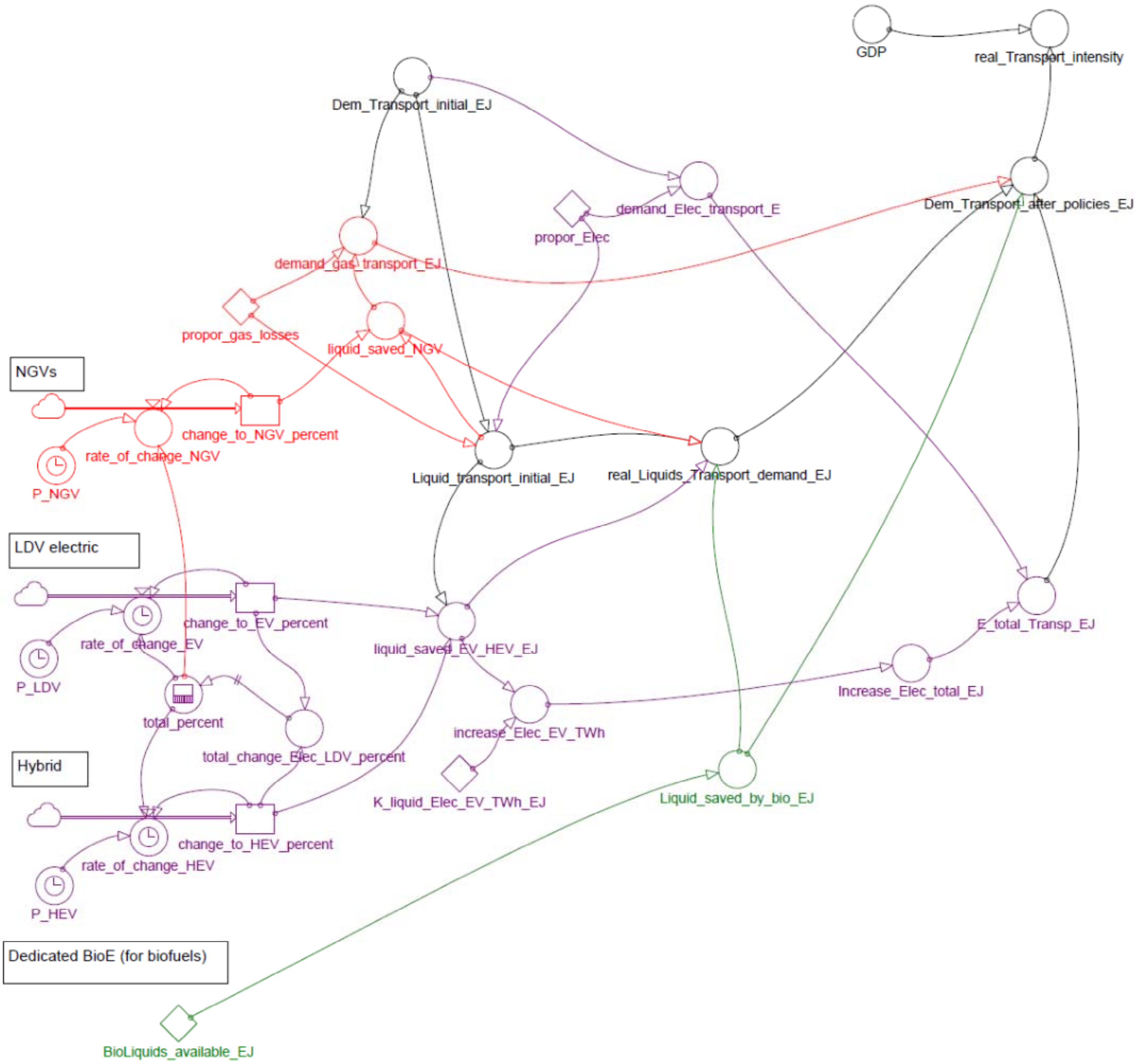


Figure 18: Forrester diagram of the Transport sector modeling in the WoLiM model.

Transportation is a key sector, which has a strong dependency on oil and is essential for most industrial processes and services, and increasingly also for the food sector (Lassaletta et al., 2014). The lack of energy for transportation is expected to have an impact on all of the other sectors, especially in a strongly globalized economy.

3.3.3. IB sectors (Industrial and Buildings)

As explained in the **section 3.2**, the energy demand of IB sectors (**Demand_IB_EJ** in **Figure 19**) is generated in aggregate form following the energy intensity method for both Industrial and Buildings sector. This is mainly due to the difficulty to find open source time series of data for each sector, but it is consistent with the approach of building a world aggregate model that contributes to the main dynamics of the energy-economy interaction. The Industry and Buildings sectors are much more complex sectors to model since they use all kinds of fuels and energy vectors in a great diversity of technologies. Consequently, we decided to focus in this version of the model on the Transport and Electricity generation sectors, while maintaining a high level of aggregation in IB sectors.

Thus, each sector energy demand share on the total TPE has remained fairly constant over the last decades, we assume that in the middle-term this proportion will hold (75% for industrial, 25% for buildings). We build a similar structure for each sector (see **Figure 19**), assuming different energy transition policies that include a switch to renewable, more efficient systems, as well as improvements in construction (e.g. in order to enhance isolation and access to natural light) or even changes at a higher level (e.g. district heating), in the same way as done in WORLD3 (Meadows et al., 2004). These policies are modeled as target-policies of market penetration level for a given year. Thus, thermal uses of renewable energies (e.g. solar, geothermal) are not explicit in the model, nor are they assigned to a concrete technology (except for the 3rd generation biomass residues detailed previously in **Section 3.1.3**).

Thermal	
Solar[1]	Geothermal
(SHC, 2012)	(WEC, 2010)
+ 21 %	+ 13 %
2000-10	1995-08

Table 8: Renewable technologies for thermal generation by source growth rates (yearly average) . [1]All types.

Both Industrial and Buildings sectors are modeled following the same structure (see Figure 19) although different policies can be applied to each one, which we describe hereafter for the Industrial sector. Thus, the total Industrial energy demand (**Industrial_EJ**) evolves following the decreasing energy intensity as described in **Section 3.2** (see **Table 6**). The variable **percent_saving_I** represents the share to the total Industrial energy demand that is concerned by the transition policies: half is assumed to involve transition to renewable sources, and half will imply energy-savings. We consider this hypothesis as realistic since in primary energy accounting, renewable sources are able to provide the same final service with less primary energy than fossil fuels (IPCC, 2011). Finally, the energy total demand from the sectors is assigned to each fuel (**I_gas, I_coal, I_oil, I_renew**) consistently with the past evolution.

For the calibration of the base year, we use the data from (IEO, 2011; WEO, 2012). In terms of renewable penetration projections for the scenarios, we use as reference the *Reference case* from (IEO, 2011) and the *New Policies scenario* from (WEO, 2012) (see Table 9).

	Reference case (IEO, 2011)		*New Policies scenario* (WEO, 2012)	
Year	2008	2035	2010	2035
Buildings	4.5%	7.4%	3.6%	10.2%
Industry	10.2%	12.6%	15.7%	12.2%

Table 9: Renewable penetration evolution following two estándar baseline scenarios .

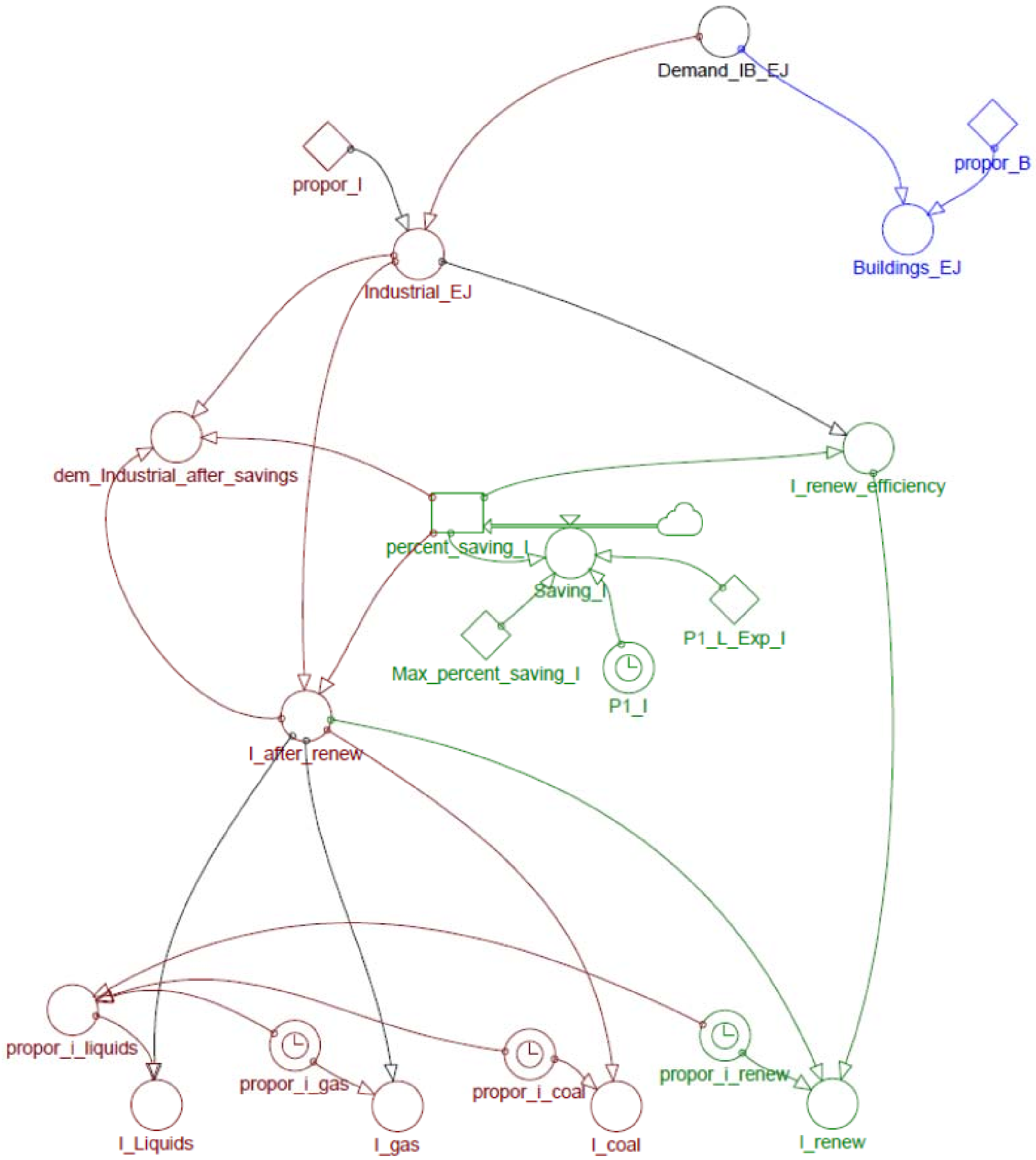


Figure 19: Forrester diagram of the representation of the Industrial sector and the policies applied.

The geothermal and solar thermal uses of renewable energies are not explicit in the model neither assigned to a concrete technology, although they are assumed to exist in both IB sectors as a transition to renewable policy. 3rd generation biomass residues modeling was detailed above and was assigned a potential for thermal uses of 20 EJ (80% conversion). However, the aggregated thermal total primary energy from renewable is tracked in the model in order to fit scenarios, at least in magnitude order, with the thermal renewable potential (see **Table 10**) estimated into 1,5 TWth (less than 45 EJ, or around 1.000 Mtoe):

		Reference	Techno-ecological potential [TWth]
Geothermal		(de Castro, 2012)	0,2
Thermal solar		Own estimation*	0,5
Thermal Biomass	3rd generation	Own estimation (25 EJ * 0.8)	0,65
	Conventional	unrestricted	

Table 10: Techno-ecological potential of non-electric renewable sources.

3.3.3.1. Industrial

This sector includes both manufacturing industries (food, paper, chemicals, refining, iron and steel, nonferrous metals, and nonmetallic minerals, among others) and nonmanufacturing industries (agriculture, mining, and construction), excluding the electricity. Chemicals, iron and steel, nonmetallic minerals, paper, and nonferrous metal manufacturing account for the majority of all industrial energy consumption. This sector accounts for around 50% of the world total final energy consumed, with a growing trend during the last decade. Interestingly, it is also the most sensitive sector (in terms of energy demand) during economic shocks, as seen in the 2007-2008 crash (IEO, 2011).

The industrial sector is dependent on a diversity of energy resources: liquid fuels, gas and coal amount each between 23% and 30%. In the last years, there has been an important growth of the renewable energy share, reaching 7% by 2007, while the share of the oil has tend to slightly decrease in favor of coal and gas (IEO, 2010). Among renewable, the most prominent source is the biomass&MSW, that provides the 90% of all the renewable energy in this sector.

3.3.3.2. Buildings: Commercial and Residential

The energy use pattern of Commercial (services sector) and Residential sectors tends to coincide in most regions (IEO, 2011) since for both the main uses are lightning, coking, heating, etc. Thus, natural gas accounts for 40% and 30%, and the electricity for 51% and 32%, respectively. Also, as depicted in the Figure 14, it is the smallest sector in terms of energy consumption, representing around 15% of the total energy demand.

In general, more potential for the penetration of alternative energies is given to the Buildings sector as usually considered (e.g. 20-20-20 from Europe Union).

However, in countries where large shares of the population still depend on the use of traditional biomass show a very different pattern (36% of the world population in 2008). We model the use of traditional biomass following the assumption of (WEO, 2010), that projects a reduction of these share to 25% in 2035 and a linear trend thereafter.

3.4. CO2 emissions and concentrations

The model computes the CO2 emissions associated with the use of fossil fuels: coefficients from (BP, 2013, p. 2013) for conventional and from (Brandt and Farrell, 2007; Howarth et al., 2011) for unconventional. Biofuels are far from being neutral carbon emitters due to Indirect Land Use Changes (ILUC); in accordance with (European Commission, 2010; Fargione et al., 2008; Haberl et al., 2012; Searchinger et al., 2008) we assign a similar emission power to natural gas.

Resource		Reference	Value [tCO2 / toe]
Coal		(BP, 2013)	3.96
CTL		(Brandt and Farrell, 2007)	6.94
Natural gas	Conventional	(BP, 2013)	2.35
	Unconventional	(Howarth et al., 2011)	3.53
GTL		(Brandt and Farrell, 2007)	4.34
Oil	Conventional	(BP, 2013)	3.07
	Unconventional	(Brandt and Farrell, 2007)	3.84 (6.14 for shale oil)

Table 11: CO2 emissions for non-renewable resources used in the model.

In this model version we implement the afforestation as the only CO2 sequestration policy. As reference we use the work from (Nilsson and Schopfhauser, 1995) that analyzed the changes in the carbon cycle that could be achieved with a large global afforestation program covering 345 Mha. Thus, a maximum carbon capture of 1.5 GtC/year 50 years after the start of the program would be attained. Other technologies such as CCS are not considered in this study due to their uncertain development and benefits (Fischedick et al., 2008; Scott et al., 2013).

In order to assess climate change, we convert the net CO2 emissions to concentration levels which assume that, in the period studied, the ocean and ground will continue to absorb 45% of total emissions as in the past (Canadell et al., 2007). Due to the high inertia and long-term scope of climate change, we extend the emission projections until 2100, as the IPCC usually does, with the aim of comparing concentration levels in at least the order of magnitude. However, since WoLiM only considers the CO2 emissions from fossil fuels (i.e. 65% of total GHG emissions in 2010 (IPCC, 2014b)), the CO2 concentration levels obtained significantly downplay the CO2-equivalente concentrations that ultimately would drive the temperature increase depending on the assumptions about climate sensitivity. Thus, the concentration level can be seen as a minimum.

3.5. Limitations of the modeling

The modeling of complex systems always implies a trade-off between simplicity and the loss of detail. Thus, uncertainties and limitations arise: some are solvable (and are targeted as "future research directions") while others are related to unavoidable judgment calls in the extrapolation of the future. Among the first are:

- **Non-inclusion of Energy Return of Energy Investment (EROEI)**: The model operates in terms of primary energy, but in reality the useful energy used by society (Net Energy) in the future may decrease at the same time as the EROEI of the non-renewable resources diminishes due to the smaller EROEI of unconventional resources (Murphy and Hall, 2010). Some modern renewable energies also perform low EROI ratios (e.g. solar (Prieto and Hall, 2013)). Thus, we do not consider here the so called "energy trap" (Murphy, 2011; Zenzey, 2013). If we would take it into account, the results would be worse (in energy terms), because the energy needed to build the infrastructure necessary for a sustainable and renewable energy system must come from current consumption of fossil fuel. Following (Zenzey, 2013, p. 80): "Unlike monetary investments, which can be made on credit and then amortized out of the income stream they produce, the energy investment in energy infrastructure must be made upfront out of a portion of the energy used today (…) The arithmetic is daunting. To avoid, for example, a 2-percent annual decline in net energy use, replacing that loss with solar photovoltaic (with an EROI pegged at 10:1) will require giving up 8 percent of the net energy available for the economy".

- **Non-inclusion of material limits and other non energetic renewable sources** (e.g. water availability (Postel, 2000), minerals (e.g. phosphorus (Cordell et al., 2009), copper (Harmsen et al., 2013)).
- **Absence of dynamic feedback between the main subsystems**. In this model version, climate impacts and energy scarcity are not fed-back to the economic system. Similar studies have shown that models are biased optimistically when feedback is omitted (e.g. (Barney, 1980; Randers, 2000)). The (MEA, 2005) report concluded that approximately 60% (15 out of 24) of the ecosystem services examined are currently being degraded or used unsustainably. Also, (Rockström et al., 2009) identifies 3 out of 10 planetary boundaries that have already been overstepped. However, high uncertainties are involved in the feedback quantification and remain beyond the scope of this paper.
- **Others:** intermittency of renewable energies, non-consideration of phenomenons such as the "energy trap", the rebound effec, conflicts (within and between countries, e.g. corruption, wars), unexpected events (e.g. natural disasters), etc.

Although in previous work the feedback energy-economy has been implemented (de Castro, 2009; de Castro et al., 2009), the reason for this simplification in this model version is the lack of consensus on the literature about the influence of energy scarcity on the economic growth. Although some authors (e.g. (Hirsch, 2008)) quantify this relationship, there is not enough historical data at a global level to identify a tendency. On the other hand, in previous studies, this feedback tends to drive the system into collapse (e.g. (de Castro, 2009; de Castro et al., 2009; Nel and Cooper, 2009)).

The omission of restrictions and feedbacks when solving a system can only lead to optimistic results. However, interesting conclusions have already been extracted and ongoing research on these issues will explore the influence of these constraints.

On the other hand, other assumptions such as the non-modeling of technology-fuel competition (through cost and efficiency as typically done in demand-driven models), might seem as in significant weakness of the model. However, since in all scenarios the peak of all fossil fuels occurs in the range of 15-20 years, the introduction of the competition would only tend to slightly delay the first "scarcity points" while hastening the last ones. In brief, for each scenario, the scarcity points for both fuels and sectors would tend to converge in time, thus, not affecting the main conclusions of the modeling exercise. However, from a societal point of view, the transition might be less challenging if the "scarcity points" are more spread in time.

3.6. Summary of the key variables of the model

Table 12 summarizse the main exogenous variables of the model.

	Exogenous variables	Description/input specification
Socioeconomic	GDPcap	GDP per capita
	Population	Population
Sectoral efficiency improvements	a_{Transp}	Annual improvement
	a_{elec}	Annual improvement
	a_{BI}	Annual improvement
	I_{min}	horizontal asymptote that represents the minimum value of the energy intensity.
Resource availability	Non-renewables	Maximum extraction curves
	CTL, GTL	Coal-to-Liquids, Gas-to-Liquids (Annual growth)
Electric renewables	Solar FV&CSP	Annual growth, available potential
	Wind	Annual growth, available potential
	Hydroelectric, Geothermal, Bioenergy&Waste	Annual growth, available potential
	Oceanic	Annual growth, available potential
Nuclear		Annual growth, restricted by uranium maximum extraction curve
BioEnergy	2nd generation	Annual growth, available potential (MHa)
	3rd generation	Annual growth
	Residues	Annual growth
Thermal renewables & efficiencies	Industrial sector	Market share in time t.
	Buildings sector	Market share in time t.
Alternative transport	HEV & Hybrid	Market share in time t.
	NGVs	Annual growth
Afforestation program		Global program (MHa available)

Table 12: Main exogenous variables in the model.

The main endogenous variables are:

- Fuel & sectoral scarcities measured with the parameter “abundance” (cf. **Section 5**),
- Climate outputs: CO2 emissions andconcentrations,
- Renewable energy for electricity investment & shares comparing to the total mix.

4. Scenario methodology

Different methods for exploring the future exist and have been applied in natural and social sciences (for an overview, see (Glenn and Gordon, 2009)). Prediction is possible if systems are well known and can be observed in controlled and reproducible situations. Unfortunately, this is not the case when complex causal relationships, limited knowledge and high level of uncertainty exist as in medium/long-term Economy-Energy-Environment modeling.

Furthermore, these predictions are contingent on drivers that may be even more difficult to predict, such as human behavior. Scenario development offers one approach to deal with all this issues, focusing on an assessment of pathways of events under a set of key assumptions ('what if'?) (van Vuuren et al., 2012).

4.1. Scenarios from Global Environmental Assessments

Scenario methodology has become very popular in recent Global Environmental Assessment (GEA) (e.g. IPCC's Assessment reports (IPCC SRES, 2000; IPCC, 2007d, 2001), UNEP's Global Environmental Outlook (UNEP, 2012, 2007, 2004) or (MEA, 2005)). The comparison of these studies shows that there is actually a limited set of scenario families that form the basis of many scenarios used in different environmental assessments. We provide below a summary of the most important characteristics of the different scenario families identified in (van Vuuren et al., 2012), describing the "qualitative" features of each scenario[13]. Table 13 summarizes the main assumptions and drivers of each scenario considered, while in Section 3 the interpretation and quantification of the scenarios is explained. A Business-as-Usual (used as reference and assuming that historical dynamics will also guide the future) and 4 scenarios are used:[14]

Scenario 1- Economic optimism with some market reforming: Strong focus on the mechanism of competitive, efficient market, free trade and associated rapid economic growth, but including some additional policy assumptions aimed at correcting some market failures with respect to social development, poverty alleviation or the environment. The scenario typically assumes rapid technology development and diffusion and convergence of income levels across the world. Economic growth is assumed to coincide with low population growth (given a rapid drop in fertility levels). Energy and material scarce resources are upgraded to reserves or substituted efficiently through market signals (price rising). Eventually, everyone will benefit from globalization and technological advances will remedy ecological problems (e.g. 'Environmental Kuznets Curve'). A major risk of this scenario family is thus that the ecological and social systems are much more sensitive than assumed, as a result of which feedback becomes important (Cumming et al., 2005; Mediavilla et al., 2013).

Scenario 2- Global Sustainable Development: Strong orientation towards environmental protection and reducing inequality, based on solutions found through global cooperation, lifestyle change and technology (more efficient technologies, dematerialization of the economy, service and information economy, etc.). Central elements are a high level of environmental and social consciousness combined with a coherent global approach to sustainable development. Within this scenario family, it is assumed that a high level of international governmental coordination is necessary and possible in order to deal with international problems like poverty alleviation, climate protection and nature conservation. It entails regulation of markets but on a global scale and based on the conviction that the Earth's limits are in sight and that therefore pro-active policies are necessary.

Scenario 3- Regional competition/regional markets*:* Scenarios in this family assume that regions will focus more on their self-reliance, national sovereignty and regional identity, leading to diversity but also to tensions between regions and/or cultures. Countries are concerned with security and protection, emphasizing primarily regional markets (protectionism, deglobalization) and paying little attention to common goods. Due to the significant reduction in technological diffusion, technological improvements progress more slowly. A key issue in these scenarios is how such self-reliance is possible without becoming harmfully ineffective with respect to supranational issues of resource depletion and environmental degradation (e.g. (Friedrichs, 2010)). As for Scenario 1, ecological feedbacks could bring "bad surprises".

[13] We have completed the descriptions from (van Vuuren et al., 2012) with the IPCC Reports on Scenario Emissions (IPCC SRES, 2000) and the (MEA, 2005).

[14] In reality (van Vuuren et al., 2012) recognize 6 scenario families. As they argue in their paper, family scenario 1 "Economic optimism/conventional markets scenarios" and 2 "Reformed market scenarios" are very similar. Thus, we decided to join them for the sake of simplicity and minimize the number of representative scenarios.

Scenario 4- Regional Sustainable Development: this scenario is the "friendly" version of the previous one, where globalization tends to be deconstructed and an important change in traditional values and social norms happens against senseless consumerism and disrespect for life. Citizens and countries must each take on the responsibilities they can bear, providing aid or setting a green example to the rest of the world, from a sense of duty, out of conviction or for ethical reasons or to solve primarily your own problems. In fact, although barriers for products are re-built, barriers for information tend to be eliminated. The focus is on finding regional solutions for current environmental and social problems, usually combining drastic lifestyle changes with decentralization of governance.

		BAU	**1- Economic optimism with some market reforming**[a]	**2- Global SD**	**3- Regional competition**	**4- Regional SD**
Economic development		Medium (historic trends)	Very rapid	Rapid	Slow	Medium
Population growth		Medium-Variant (UN, 2011)	Very low	Low	Similar to (UN, 2011) Medium-Variant	Similar to (UN, 2011) Medium-Variant
Technology development		Medium	Rapid	Ranging from mid to rapid	Slow	Ranging from low to rapid
Main objectives		Not defined	Various goals	Global sustainability	Security	local sustainability
Environmental protection		Both reactive and proactive	Mainly reactive	Proactive	Reactive	proactive
Trade		Weak globalization	Globalization	Globalization	Trade barriers	Trade barriers
Policies and institutions		Mixed	Policies to create open markets and reduce market failures	Strong global governance	Strong national governments	local steering; local actions
Examples in GEAs	(IPCC SRES, 2000)	-	A1	B1	A2	B2
	(MEA, 2005)	-	Global Orchestration	Techno-Garden	Order from Strength	Adapting Mosaic

Table 13: This table summarizes the main assumptions and drivers in very general terms. [a]**We have merged the categories "Economic Optimism" and "Reforming Markets" because of their similarity for the sake of simplicity as justified by (van Vuuren et al., 2012). When a range was given, we have either referred directly to the quantification by (MEA, 2005) for socioeconomic inputs, or made our own interpretation as discussed in the text above.**

4.2. Scenario implementation

Three main steps are applied when implementing a scenario with the WoLiM 1.0 model:

1- Selection (or self-construction) of a consistent (qualitative) storyline framework. For example, the storylines from the Global Environmental Assessments (e.g. IPCC, MEA, etc.).

2- Interpretation/quantification of the storyline. Typically, the socioeconomic inputs GDPcap and Population are available from the Global Environmental Assessments or institutional research agencies (e.g. IPCC, (MEA, 2005), United Nations, etc.).
3- For the rest of variables not explicitly available from GEAs, we will have to interpret each storyline quantifying specific transition policies and technology aspects (cost, availability, etc.) in our model.

5. Results interpretation

In order to deal with the divergences between energy demand and supply, we define the parameter "abundance" for quantifying the relative scarcity by fuel and economic sector:

- By non-renewable fuel i: as a relation between the maximum extraction (Maximum extraction$_i$) as defined in **Section 3.1.1** and the total fuel demand (Demand$_i$) of each scenario (**equation (8)**):

$$Abundance(t)_i = \frac{(Maximum\ extraction(t)_i - Demand(t)_i)}{Demand(t)_i} \qquad \text{equation (8)}$$

- By renewable fuel i: is a relation between the potential considered and the current level extracted (**equation (9)**):

$$Abundance(t)_i = \frac{(Potential_i - TWe(t)_i)}{Potential_i} \qquad \text{equation (9)}$$

- By sector j: as a relation between each sectoral demand driven by each scenario (Demand$_j$) and the energy effectively extracted to fulfill the demand for this sector j (Demand$_j$) (**equation (10)**):

$$Abundance(t)_j = \frac{(Energy\ extraction(t)_j - Demand(t)_j)}{Demand(t)_j} \qquad \text{equation (10)}$$

Thus, while "abundance" is higher than 0, supply and demand are balanced. However, when abundance becomes negative it is because demand cannot be fulfilled.

In order to analyze the supply constraints on the demand of each sector and energy resources for all scenarios, we represent the "Energy Scarcity Matrix". For each economic sector and nonrenewable resource, each point represents the date when the relative difference between the demand and supply is greater than 5%. We select 5% as a qualitative threshold as it is when the price-mechanism adaptation could force important socio-economic structural changes that would modify the underlying hypothesis of the scenarios and the model.[15] For renewable resources, each point represents the date when 95% of the potential is reached.

6. Conclusion and future developments

This report documents the first version of the WoLiM (World Limits Model), which main focus is the study of the different future energy development constraints in an dynamic integrated way with the socioeconomic system and the climate. Ongoing and future research and developments will focus into:

- Integration of dynamic feedbacks: e.g. energy supply and demand interactions for each sector, impacts of climate change in the economy.

[15] e.g. (Hamilton, 2011) reports shortfalls in production in past oil shocks since the 70s between 5 and 10%. However, most of these oil shocks were sudden and temporary due to geopolitical factors (OPEC decision, wars, etc.); thus representing a very different panorama comparing to the scenario reported here: systemic scarcity risk.

- Integration of alternative economics paradigms: e.g. the Steady-State economy as complement of Degrowth theory (Daly, 1996; Kerschner, 2010), the New Economics of Prosperity (Jackson, 2009) and Degrowth (Latouche, 2009)). If the nature of human behavioural challenges is a typical ''tragedy of the commons'' problem (a phenomenon for which (Hardin, 1968) argues there are no technical solutions), no-technical-solutions should be explored.
- Integration of EROI of energy resources (Murphy and Hall, 2010; Prieto and Hall, 2013) and other limits (e.g. water availability (Postel, 2000), phosphorus (Cordell et al., 2009), etc.).

Appendix A. Basic structure of the model

Figures A1 and A2 show an overview of the Forrester diagram of WoLiM where the main relationships and subsystems can be seen. Demands are shown in green, non renewable resources in light blue, renewable electricity in dark blue, policies in red and emissions in orange[16].

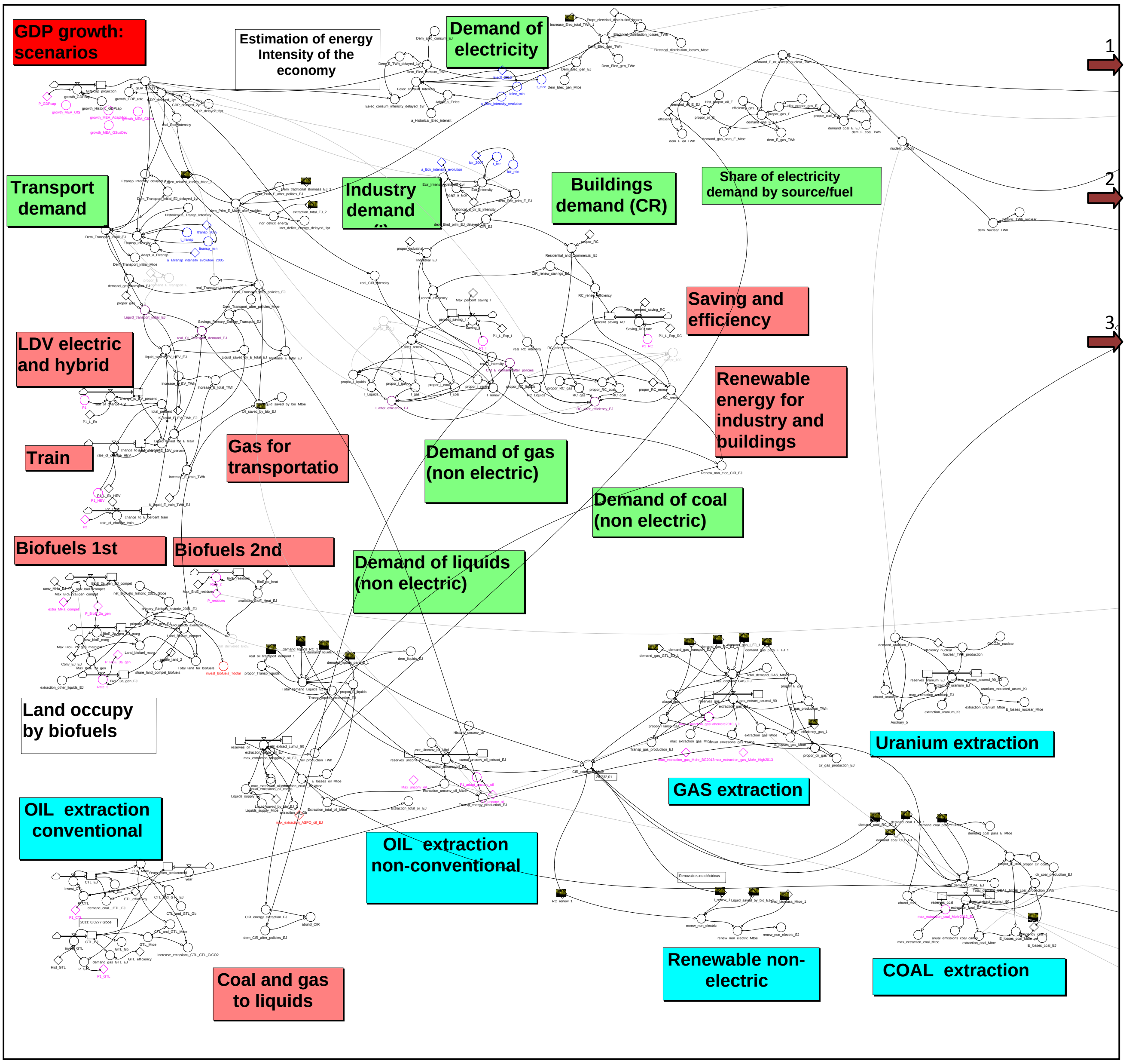


Figure A1: Forrester diagram of WoLiM model (left side). Stocks are represented as squares, flows by the arrows related to stocks, variables are represented by circles and constants by rhombus. Most of the relationships between variables are represented by lines but some are hidden for simplicity.

[16] For a complete description of the model, please see (Capellán-Pérez et al., 2014). http://www.eis.uva.es/energiasostenible/?page_id=2056

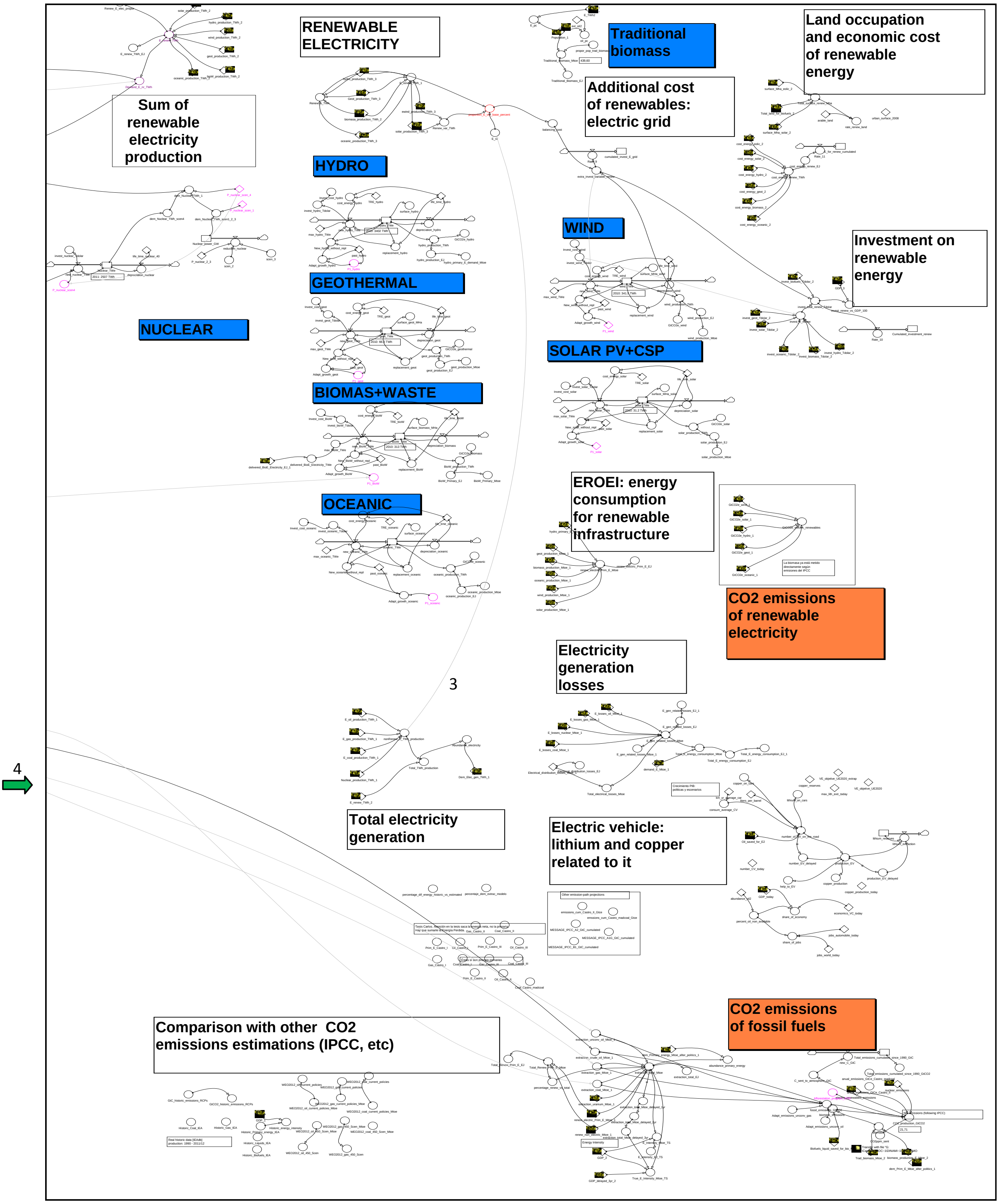


Figure A2: Forrester diagram of WoLiM model (right side). Stocks are represented as squares, flows by the arrows related to stocks, variables are represented by circles and constant by rhombus. Most of the relationships between variables are represented by lines but some are hidden in order to simplify the graph.

Appendix B: Econometric estimations of sectoral energy demands

Total PE demand:

Modelo 2: MCO, usando las observaciones 1972-2010 (T = 39)
Variable dependiente: Itot

	Coeficiente	Desv. Típica	Estadístico t	Valor p	
Itot_1	0,988582	0,00202720	487,7	9,45e-074	***

Media de la vble. dep.	11,61510	D.T. de la vble. dep.	1,611948
Suma de cuad. residuos	0,856381	D.T. de la regresión	0,150121
R-cuadrado	0,999840	R-cuadrado corregido	0,999840
F(1, 38)	237811,3	Valor p (de F)	9,45e-74
Log-verosimilitud	19,12412	Criterio de Akaike	-36,24825
Criterio de Schwarz	-34,58468	Crit. de Hannan-Quinn	-35,65137
rho	0,011045	h de Durbin	0,068093

Transport PE demand:

Modelo 1: MCO, usando las observaciones 1972-2005 (T = 34)
Variable dependiente: Itransp

	Coeficiente	Desv. Típica	Estadístico t	Valor p	
Itransp_1	0,992764	0,00217595	456,2	2,76e-064	***

Media de la vble. dep.	2,207511	D.T. de la vble. dep.	0,161665
Suma de cuad. residuos	0,026399	D.T. de la regresión	0,028284
R-cuadrado	0,999841	R-cuadrado corregido	0,999841
F(1, 33)	208158,6	Valor p (de F)	2,76e-64
Log-verosimilitud	73,48942	Criterio de Akaike	-144,9788
Criterio de Schwarz	-143,4525	Crit. de Hannan-Quinn	-144,4583
rho	0,053937	h de Durbin	0,309870

Electricity generation:

Modelo 2: MCO, usando las observaciones 1981-2005 (T = 25)
Variable dependiente: Ielec

	Coeficiente	Desv. Típica	Estadístico t	Valor p	
Ielec_1	1,00127	0,00187635	533,6	2,07e-050	***

Media de la vble. dep.	350,4258	D.T. de la vble. dep.	4,184721
Suma de cuad. residuos	258,7547	D.T. de la regresión	3,283511
R-cuadrado	0,999916	R-cuadrado corregido	0,999916
F(1, 24)	284759,4	Valor p (de F)	2,07e-50
Log-verosimilitud	-64,68602	Criterio de Akaike	131,3720
Criterio de Schwarz	132,5909	Crit. de Hannan-Quinn	131,7101
rho	-0,226293	h de Durbin	-1,108652

Table B1: Econometric estimations of sectoral energy demands

Appendix C: Adaptation of WoLiM model to coal unlimited extraction scenarios

In the standard version WoLiM version, fuel substitution mechanisms between fossil fuels where not implemented in the IB (Industrial and Buildings) sectors for the sake of simplicity. In fact, when all fossil fuels are constrained their peak production is reached at different dates. However, the modeling of these fuel substitution mechanisms in these sectors would only accelerate the depletion of the more lasting fuels (gas and coal). Thus, the essential conclusions would remain unchanged. However, when assuming unconstrained coal resources, these mechanisms are essential in order to allow for a transition to a carbon-based economy. We assume that when gas and coal scarcity approaches to a critical level, there would be a switch to coal in the IB end-use sectors (1% annual each from gas and liquids to coal).

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Equations of WoLiM model

init BioE_2a_gen_EJ_compet = 1182.1*(365/1000000)*5.582

flow BioE_2a_gen_EJ_compet = +dt*new_bioE_compet

doc BioE_2a_gen_EJ_compet = 142.44 Kb/d según [BP2012] en 1990. Conversión a Mb/año y EJ/año 1182,1 Kb/d en 2011.

init BioE_2a_gen_EJ_marg = 10*(365/1000000)*5.582

flow BioE_2a_gen_EJ_marg = +dt*new_bioE_marg

doc BioE_2a_gen_EJ_marg = 142.44 Kb/d según [BP2012] en 1990. Conversión a Mb/año y EJ/año 1182,1 Kb/d en 2011.

init BioE_3a_gen_EJ = 0.1

flow BioE_3a_gen_EJ = +dt*Rate_3

init BioE_residues = 0.3

flow BioE_residues = +dt*Rate_2

init BioW_TWe = 90.55/(365*24)

flow BioW_TWe = +dt*new_BioW_TWe

-dt*depreciation_biomass

doc BioW_TWe = TWh consumidos en 1990 [tonto.eia]: 90.5. de Biomass + waste

init change_to_E_percent_train = 0

flow change_to_E_percent_train = +dt*rate_of_change_train

doc change_to_E_percent_train = Vamos a suponer que todo el transporte actual eléctrico es por tren. Así, del total de energía dedicada a transporte de media entre el 1990 y el 2008 el 1% es eléctrico. Pero no lo consideramos aquí sino en "Transport EJ" minorándolo un 1%, pues esta demanda ya está considerada en la demanda eléctrica "demand_E_TWh".

init change_to_EV_percent = 0.00007

flow change_to_EV_percent = +dt*rate_of_change_EV

doc change_to_EV_percent = [EVI EIA 2013] en 2012.

init change_to_HEV_percent = 0.00007

flow change_to_HEV_percent = +dt*rate_of_change_HEV

init change_to_NGV_percent = 0.00028

flow change_to_NGV_percent = +dt*rate_of_change_NGV

doc change_to_NGV_percent = Despite the strong growth in the past decade, the total number of 16.7 million NGVs (http://www.iangv.org/current-ngv-stats/) still pales in comparison to a total worldwide number of around 1,150 million motor vehicles in 2009 (World Bank database, 2014). - 1.45% of total.

init CO2ppm = 354.35

flow CO2ppm = +dt*CO2ppm_atm_increase

doc CO2ppm = ppm in 1990 [Mauna Loa]

init coal_extract_acumul_90 = 0

flow coal_extract_acumul_90 = +dt*extraction_coal_EJ

doc coal_extract_acumul_90 = Coal extraído desde 1990 (EJ)

init CTL_EJ = 0.0365*5.582

flow CTL_EJ = +dt*invest_CTL

doc CTL_EJ = Producción en 1990 [WEO2012]=0.1 Mb/d=0.0365 Gboe/año. Producción en 2011 [WEO2012]=0.2 Mb/d=0.073 Gboe/año.

init cumul_unconv_oil_extract_EJ = 0.96*365*5.582/1000

flow cumul_unconv_oil_extract_EJ = +dt*extraction_unconv_oil_EJ

doc cumul_unconv_oil_extract_EJ = Producción en 1990 de unconventional oil: 0.4 Mb/d [WEO2012].

init Cumulated_demand_GAS_EJ = 0

flow Cumulated_demand_GAS_EJ = +dt*Rate_16

init cumulated_invest_E_grid = 0

flow cumulated_invest_E_grid = +dt*Rate_9

init Cumulated_investment_renew = 0

flow Cumulated_investment_renew = +dt*Rate_10

init E_for_renew_cumulated = 0

flow E_for_renew_cumulated = +dt*Rate_11

init gas_extract_acumul_90 = 0

flow gas_extract_acumul_90 = +dt*extraction_gas_EJ

doc gas_extract_acumul_90 = Gas extraído desde 1990 (EJ)

init GDPcap_projection = 7.654143476

flow GDPcap_projection = +dt*growth_GDPcap

doc GDPcap_projection = 2011 UST$ per capita del WorldBank en 1990. Datos en: WORLD MODEL _ paper solutions\Equity graphs\GDP_defaltor (ejemplo_Oscar)3.xls

init geot_TWe = 35.82/(365*24)

flow geot_TWe = +dt*new_geot_TWe

-dt*depreciation_geot

doc geot_TWe = TWe consumidos en 1990 [Base de datos tonto.eia].

init GTL_EJ = 0.001*5.582

flow GTL_EJ = +dt*invest_GTL

doc GTL_EJ = Producción en 2011 [WEO2012]=0.076 Mb/d=0.0277 Gboe/año

init hydro_TWe = 2144.5/(365*24)

flow hydro_TWe = -dt*depreciation_hydro

+dt*new_hydro_TWe

doc hydro_TWe = 2144.5/(365*24) TWe consumidos en 1990 [5.12].

init lithium_reserves = 11e9

flow lithium_reserves = -dt*lithium_extraction

doc lithium_reserves = Pongo 11e9Kg de reservas base, lo del US Geological Survey, suponiendo que van a ser extraibles. En los datos hay mucha disparidad, las viables ahora serian unas 6.8e9 segun 4.7, ------según PPP 4.1 25,5e9 Kg de litio (5,2 toneladas de carbonato por cada tonelada de litio).

segun 4.7 ETC reserva base extraible o no: entre 11e9 - 17e9 y 30 e9 Kg

reservas explotables ahora economicamente viables: 4,1e9Kg + 2,7e9Kg (Bolivia)

init Nuclear_power_GW = 374

flow Nuclear_power_GW = -dt*reduction_nuclear

init Nuclear_TWe = 2507/(365*24)

flow Nuclear_TWe = -dt*depreciation_nuclear

+dt*new_nuclear_TWe

doc Nuclear_TWe = 2507/(365*24) TWe consumidos en 2011 [EIAdb].

init oceanic_TWe = 1/(365*24)

flow oceanic_TWe = +dt*new_oceanic_TWe

-dt*depreciation_oceanic

doc oceanic_TWe = TWe consumidos en 2007 [5.12].

init Oil_extract_cumul_90 = 0

flow Oil_extract_cumul_90 = +dt*extraction_crude_oil_EJ

doc Oil_extract_cumul_90 = Oil extraído hasta 1990.

init percent_saving_I = 0

flow percent_saving_I = +dt*Saving_I

doc percent_saving_I = Consideramos las energías renovables empleadas en el sector Industrial como Ahorro-Eficiencia.

init percent_saving_RC = 0

flow percent_saving_RC = +dt*Saving_RC_rate

doc percent_saving_RC = Consideramos las energías renovables empleadas en los sectores Residencial y Comercial como Ahorro-Eficiencia.

init Population = 5.296211383e9

flow Population = +dt*pop_growth

doc Population = En 1990 la poblacion mundial era de 5.2e9 habitantes (WorldBank-UN). Datos en: Investigación - Bibliografia\Socioeconomic inputs/GDP y Pop inputs.xlsx

init reserves_coal = (28000-4400)

flow reserves_coal = -dt*extraction_coal_EJ

doc reserves_coal = URR de Mohr2012: 670 Gtoe=27800 EJ. En 1990 la extracción acumulada fue de 90Gtoe=4400 EJ. In 2007, la extracción acumulada fue de 148 Gtoe=6210 EJ.

init reserves_gas = 13600-1500

flow reserves_gas = -dt*extraction_gas_EJ

doc reserves_gas = Según [Laherrere2010], la URR es de 13.000 tcf=13600 EJ. Extracción acumulada en 1990: 1500 EJ (en 2007: 2725 tcf = 2850 EJ). Por lo que en 2007 quedaban disponibles 10275tcf=10750 EJ.

init reserves_oil = 14500-3750

flow reserves_oil = -dt*extraction_crude_oil_EJ

doc reserves_oil = En 1990: extracción acumulada 3750 EJ (en 2007: 1100 Gb (= 6500 EJ)), se supone que las reservas totales extraibles (URR) son de entre 1900 y 2600 Gb segun ASPO o CERA u otros. Tomando la curva de ASPO y anulando la extracción en 2100 sale un URR de 2300 Gb (= 12 800 EJ).

init reserves_unconv_oil_EJ = 750*5.582

flow reserves_unconv_oil_EJ = -dt*extraction_unconv_oil_EJ

doc reserves_unconv_oil_EJ = 750 Gb

init reserves_uranium_EJ = 3900-755

flow reserves_uranium_EJ = -dt*extraction_uranium_EJ

doc reserves_uranium_EJ = 3900 Según [Zittel2012] (curvas_recursos.xlsx). Uranio extraído hasta 1990: 1770 kt U (=755 EJcaloríficos)

init solar_TWe = 1/(365*24)

flow solar_TWe = +dt*new_solar_TWe

-dt*depreciation_solar

doc solar_TWe = 1 TWh consumidos en 2007 [tonto.eia].

init Total_emissions_cumulated_since_1990_GtC = 0

flow Total_emissions_cumulated_since_1990_GtC = +dt*new_C_GtC

init uranium_extract_acumul_90_EJ = 0

flow uranium_extract_acumul_90_EJ = +dt*extraction_uranium_EJ

init wind_TWe = 3.54/(365*24)

flow wind_TWe = +dt*new_wind_TWe

-dt*depreciation_wind

doc wind_TWe = 3.5 TWh producidos en 1990 [EIAdb]: 0.0189 TWe.

init Years_from_peakconvoil = 0

flow Years_from_peakconvoil = +dt*year

aux CO2ppm_atm_increase = 0.45*(1/7.8)*CO2_production_GtCO2

doc CO2ppm_atm_increase = Según [Canadell 2007], el 45% de las emisiones de CO2 han ido en el pasado a la atmósfera (y el 55% a los océanos).

aux depreciation_biomass = BioW_TWe/life_time_BioW

doc depreciation_biomass = retardo material en el deterioro de las nuevas infraestructuras

aux depreciation_geot = geot_TWe/life_time_geot

doc depreciation_geot = retardo material en el deterioro de las nuevas infraestructuras

aux depreciation_hydro = hydro_TWe/life_time_hydro

doc depreciation_hydro = retardo material en el deterioro de las nuevas infraestructuras

aux depreciation_nuclear = Nuclear_TWe/life_time_nuclear_40

doc depreciation_nuclear = retardo material en el deterioro de las nuevas infraestructuras DELAYMTR(Nuclear_TWe, life_time_nuclear_40*0,3)*(1/life_time_nuclear_40)

aux depreciation_oceanic = oceanic_TWe/life_time_oceanic

doc depreciation_oceanic = retardo material en el deterioro de las nuevas infraestructuras

aux depreciation_solar = solar_TWe/life_time_solar

doc depreciation_solar = retardo material en el deterioro de las nuevas infraestructuras DELAYMTR(solar_TWe, life_time_solar)*(1/life_time_solar)

aux depreciation_wind = wind_TWe/life_time_wind doc depreciation_wind = retardo material en el deterioro de las nuevas infraestructurasDELAYINF(eolic_TWe, life_time_eolic,1,0)*(1/life_time_eolic)

aux extraction_coal_EJ = MIN(Total_demand_COAL_EJ,max_extraction_coal_Mohr2012_EJ)

doc extraction_coal_EJ = Extracción de carbón anual.

aux extraction_crude_oil_EJ = MIN(Total_demand_OIL_EJ,max_extraction_H_Maggio12_oil_EJ)

doc extraction_crude_oil_EJ = Extracción de petróleo anual.

aux extraction_gas_EJ = MIN(Total_demand_GAS_EJ,max_extraction_gasLaherrere2010_EJ)

doc extraction_gas_EJ = Extracción de gas natural anual.

aux extraction_unconv_oil_EJ = IF(TIME<2011,Historic_unconv_oil,MAX(4.72*(1+P1_adapt_unconv_oil)^(TIME-2010),0))

doc extraction_unconv_oil_EJ = IF(TIME<2011,Unconv_oil_extract_EJ*Historic_unconv_oil_growth,Unconv_oil_extract_EJ*P1_unconv_oil)

aux extraction_uranium_EJ = MIN(demand_uranium_EJ,max_extraction_uranium_EJ)

doc extraction_uranium_EJ = Extracción de uranio anual.

aux growth_GDPcap = IF(TIME>2010,P_GDPcap*GDPcap_projection,GDPcap_projection*growth_Historic_GDPcap)

doc growth_GDPcap = T$ PPP 2000/yr

aux invest_CTL = IF((TIME>2011),CTL_EJ*P_CTL,CTL_EJ*Hist_CTL)

doc invest_CTL = IF((TIME>2011),CTL_EJ*P1_CTL*(max_CTL_EJ-CTL_EJ)/max_CTL_EJ,CTL_EJ*Hist_CTL)

aux invest_GTL = IF((TIME>2011),GTL_EJ*P_GTL,Hist_GTL*GTL_EJ)

aux lithium_extraction = IF(lithium_reserves>0,(production_EV_delayed+production_EV)*12,0)

doc lithium_extraction = Lo dejamos en 12 Kg litio por vehiculo, una media entre los valores de diversas fuentes PPP 4.1 -- 11,5 Kg de litio por coche y se gastan dos juegos de baterias en los 11 años de vida útil.

4.7 habla de 15 Kg litio/vehiculo,

y otras estimaciones: 2,23 Kg litio/vehiculos para coches pequeños

y grandes: 9 Kg/vehiculo

Estas estimaciones estan entre los 9 y los 15 Kg de litio por vehiculo, estando PPP en medio con 11,5.

aux new_bioE_compet = IF(TIME<2011,0,IF(TIME<2015,0.08,P_BioE_2a_gen*BioE_2a_gen_EJ_compet*(Max_BioE_2a_gen_compet-BioE_2a_gen_EJ_compet)/Max_BioE_2a_gen_compet))

aux new_bioE_marg =
IF(TIME<2011,0,IF(TIME<2015,0.08,P_BioE_2a_gen*BioE_2a_gen_EJ_marg*(Max_BioE_2a_gen_marginal-BioE_2a_gen_EJ_marg)/Max_BioE_2a_gen_marginal))

aux new_BioW_TWe =
IF(BioW_TWe<max_BioW_TWe,replacement_BioW+New_BioW_without_repl*(max_BioW_TWe-BioW_TWe)/(max_BioW_TWe),0)

doc new_BioW_TWe = Nueva potencia instalada anualmente (sigue una curva que a medida que se acerca al techo de producción modera su crecimiento)

aux new_C_GtC = C_sent_to_atmosphere_GtC

aux new_geot_TWe =
IF(geot_TWe<max_geot_TWe,replacement_geot+New_geot_without_repl*(max_geot_TWe-geot_TWe)/(max_geot_TWe),0)

doc new_geot_TWe = Nueva potencia instalada anualmente (sigue una curva que a medida que se acerca al techo de producción modera su crecimiento)

aux new_hydro_TWe =
IF(hydro_TWe<max_hydro_TWe,replacement_hydro+New_hydro_without_repl*(max_hydro_TWe-hydro_TWe)/(max_hydro_TWe),0)

doc new_hydro_TWe = Nueva potencia instalada anualmente (sigue una curva que a medida que se acerca al techo de producción modera su crecimiento). hydro_TWe*

aux new_nuclear_TWe = IF(Auxiliary_5>0,Nuclear_TWe*P_nuclear_scen4,0)

doc new_nuclear_TWe = Nueva potencia instalada anualmente (sigue una curva que a medida que se acerca al techo de producción modera su crecimiento). IF(Auxiliary_5>0,Nuclear_TWe*P_nuclear_scen4,0)

aux new_oceanic_TWe =
IF(oceanic_TWe<max_oceanic_TWe,replacement_oceanic+New_oceanic_without_repl*(max_oceanic_TWe-oceanic_TWe)/(max_oceanic_TWe),0)

doc new_oceanic_TWe = Nueva potencia instalada anualmente (sigue una curva que a medida que se acerca al techo de producción modera su crecimiento)

aux new_solar_TWe =
IF(solar_TWe<max_solar_TWe,replacement_solar+New_solar_without_repl*(max_solar_TWe-solar_TWe)/(max_solar_TWe),0)

doc new_solar_TWe = Nueva potencia instalada anualmente (sigue una curva que a medida que se acerca al techo de producción modera su crecimiento)

aux new_wind_TWe =
IF(wind_TWe<max_wind_TWe,replacement_wind+New_wind_without_repl*(max_wind_TWe-wind_TWe)/(max_wind_TWe),0)

doc new_wind_TWe = Nueva potencia instalada anualmente (sigue una curva que a medida que se acerca al techo de producción modera su crecimiento)

aux pop_growth = IF(TIME<2011,Population*growth_historic_Pop,Population*growth_pop) aux Rate_10 = IF(TIME>1990,invest_total_renew_Tdolar,0)

aux Rate_11 = cost_energy_renew_EJ

aux Rate_16 = Total_demand_GAS_EJ

aux Rate_2 = IF(TIME<2025,0,P_residues*BioE_residues*(Max_BioE_residues-BioE_residues)*1.5/Max_BioE_residues)

aux Rate_3 = IF(TIME<2025,0,P_BioE_3a_gen*BioE_3a_gen_EJ*(Max_BioE_3a_gen-BioE_3a_gen_EJ)*1.5/Max_BioE_3a_gen)

doc Rate_3 = Fuerzo la expresión para que en 15 se sustituyan a nivel mundial los biofuels de 2a generación por los de 1a.

aux Rate_9 = extra_invest_variable_renew

aux rate_of_change_EV = IF((TIME>2012) AND (total_percent<0.448), (IF(P1_L_Ex=1, P1, P1*change_to_EV_percent)),0)

doc rate_of_change_EV = [límite de sustitución: 0.448] Tomo policies lineales, en x años un y% de sustitucon, limite en el 95,4% (5.12) de la energia (la parte de la demanda de transporte cubierta por petróleo) y lo minoro el 47% (4.7) porque es la proporcion de consumo correspondiente a los vehiculos ligeros (coches, furgonetas, 4x4, etc): 0,47*0,954=0,448

aux rate_of_change_HEV = IF((TIME>2012) AND (total_percent<0.448), (IF(P1_L_Ex_HEV=1, P1_HEV, P1_HEV*change_to_HEV_percent)),0)

doc rate_of_change_HEV = [límite de sustitución: 0.448] Tomo policies lineales, en x años un y% de sustitucon, limite en el 60% d ela energia (lo actualmente destinado de petroleo a transporte) pero no tomo 60% sino solo 30% porque estimo que es la proporcion de consumo correspondiente a los vehiculos ligeros y coches (furgonetas 4x4, etc)

aux rate_of_change_NGV = IF((total_percent+change_to_NGV_percent<1), P_NGV*change_to_NGV_percent,0)

doc rate_of_change_NGV = [límite de sustitución: 0.448] Tomo policies lineales, en x años un y% de sustitucon, limite en el 60% d ela energia (lo actualmente destinado de petroleo a transporte) pero no tomo 60% sino solo 30% porque estimo que es la proporcion de consumo correspondiente a los vehiculos ligeros y coches (furgonetas 4x4, etc)

aux rate_of_change_train = IF((TIME>2010) AND (change_to_E_percent_train<0.242), (IF(P2_L_Ex=1, P2, P2*change_to_E_percent_train)),0)

doc rate_of_change_train = Tomo policies lineales, en x años un y% de sustitucon, limite en el 95,4% (IEO 2010) de la energia (la parte de la demanda de transporte cubierta por petróleo) y lo minoro al 22,2% ("Transport, Energy and CO2") porque es la proporcion de consumo correspondiente a los camiones de mercancías: 0,222*0,954=0,212 A esta cantidad le tengo que sumar la parte del transporte ferroviaria que no utilizaba en 2007 electricidad (diésel principalmente, y algo de carbón -en China-). En 2006 del total de energía necesario para el transporte por tren, tan sólo el 31% se cubría mediante electricidad (17% en 1990). Por lo que le sumamos un factor 1% * 3 = 3% quedando 0,212+0,03=0.242

aux reduction_nuclear = IF(TIME<2007,0,IF(P_nuclear_2_3<1,scen_2,scen_3))

aux Saving_I = IF(percent_saving_I<Max_percent_saving_I,(IF(P1_L_Exp_I=1, P1_I, P1_I*percent_saving_I)),0)

aux Saving_RC_rate = IF(percent_saving_RC<Max_percent_saving_RC,(IF(P1_L_Exp_RC=1, P1_RC, P1_RC*percent_saving_RC)),0)

aux year = IF(Abund_liquids<0,1,0)

aux a_Elec_intensity_evolution = IF(TIME<2020,1,1)

doc a_Elec_intensity_evolution = IF(TIME<2020,1,0.995) Escenario tendencias históricas: mantenemos la intensidad cte en 420 TWh/T$. Si queremos introducir un escenario de mejora de intensidad a partir del 2025, ponemos (1-reducción intensidad energética anual), que en primera aproximación ponemos del 0.5% anual --> 0.995.

aux a_Historical_Elec_intensit = GRAPH(TIME,1990,1,[0.9919245,1.005085,0.9862358,1.005503,0.9905932,1.006595,0.9968513,0.9885938,1.003211,0.9921935,1.001247,1.000037,1.014262,1.006506,1.007933,1.004644,0.9997264,1.006729,1.003361,1.018139,1.016389"Min:0;Max:1"])

doc a_Historical_Elec_intensit = Cálculo del parámetro "a" anual en el periodo 1990-2010: a=I(t)/I(t-1). Calculado en Investigación - Bibliografia\Socioeconomic inputs e Intensidades/GDP_Pop_intensities inputs.xlsx

aux A1 = GRAPH(TIME,1990,10,[21.96754,25.28659,30.48082,38.71046,48.43741,56.87467,60.3959,65.4187,68.68429,65.48585,56.67879,50.6995"Min:0;Max:1"])

aux A2 = GRAPH(TIME,1990,10,[21.96754,25.28659,30.5736,37.84777,45.03211,50.08459,55.39082,60.34123,67.3817,77.368,91.30138,103.439"Min:0;Max:1"])

aux abund_BioW = (max_BioW_TWe-BioW_TWe)/max_BioW_TWe

aux abund_CIR = (CIR_energy_extraction_EJ-dem_CIR_after_policies_EJ)/dem_CIR_after_policies_EJ

aux abund_coal = IF(Total_demand_COAL_EJ>1,(max_extraction_coal_Mohr2012_EJ-Total_demand_COAL_EJ)/Total_demand_COAL_EJ,1)

doc abund_coal = Abundancia de carbón. Si es positiva, nos indica que aún tenemos más capacidad de extracción. Si es negativo, que la capacidad es máxima y aún así la demanda es mayor, por lo que no se satisface.

aux Abund_electricity = IF(TIME<2015,0,(Total_TWh_production-Dem_Elec_gen_TWh_1)/Dem_Elec_gen_TWh_1)

doc Abund_electricity = IF because there is a mismatch in the calibration in 2011 that causes that, that year, the abund(electricity)<-0.05.

aux abund_gas = IF(Total_demand_GAS_EJ>1,(max_extraction_gasLaherrere2010_EJ-Total_demand_GAS_EJ)/Total_demand_GAS_EJ,1)

doc abund_gas = Abundancia de gas natural. Si es positiva, nos indica que aún tenemos más capacidad de extracción. Si es negativo, que la capacidad es máxima y aún así la demanda es mayor, por lo que no se satisface.

aux abund_geot = (max_geot_TWe-geot_TWe)/max_geot_TWe

aux abund_hydro = (max_hydro_TWe-hydro_TWe)/max_hydro_TWe aux Abund_liquids = IF(Total_demand_Liquids_EJ>1,(max_extraction_H_Maggio12_oil_EJ+Other_liquids_EJ-Total_demand_Liquids_EJ)/Total_demand_Liquids_EJ,1)

doc Abund_liquids = Abundancia de petróleo. Si es positiva, nos indica que aún tenemos más capacidad de extracción. Si es negativo, que la capacidad es máxima y aún así la demanda es mayor, por lo que no se satisface.

aux abund_oceanic = (max_oceanic_TWe-oceanic_TWe)/max_oceanic_TWe

aux abund_solar = (max_solar_TWe-solar_TWe)/max_solar_TWe

aux abund_TPE = (extraction_total_Mtoe-dem_Primary_energy_Mtoe_after_politics_1)/dem_Primary_energy_Mtoe_after_politics_1

aux abund_Transport = (Transp_energy_production_EJ-dem_Transport_after_policies_EJ_1)/dem_Transport_after_policies_EJ_1

doc abund_Transport = (Total_TWh_production-Dem_Elec_gen_TWh_1)/Dem_Elec_gen_TWh_1

aux abund_uranium = IF(demand_uranium_EJ>1,(max_extraction_uranium_EJ-demand_uranium_EJ)/demand_uranium_EJ,1)

doc abund_uranium = Abundancia de uranio. Si es positiva, nos indica que aún tenemos más capacidad de extracción. Si es negativo, que la capacidad es máxima y aún así la demanda es mayor, por lo que no se satisface.

aux abund_wind = (max_wind_TWe-wind_TWe)/max_wind_TWe

aux Adapt_a_Ecir = IF(TIME<2020,Historical_a_cir_E_intensity+(a_Ecir_intensity_evolution-a_Ecir_intensity_evolution)*(TIME-2010)/10,a_Ecir_intensity_evolution)

doc Adapt_a_Ecir = IF(TIME<2020,past_eolic+(P1_eolic_bueno-past_eolic)*(TIME-2010)/10,P1_eolic_bueno) IF(TIME<2015,past_eolic+(P1_eolic-past_eolic)*(TIME-2010)/5,P1_eolic)

aux Adapt_a_Eelec = IF(TIME<2011,a_Historical_Elec_intensit,IF(TIME<2020,1+(a_Elec_intensity_evolution-1)*(TIME-2010)/10,a_Elec_intensity_evolution))

doc Adapt_a_Eelec = IF(TIME<2020,past_eolic+(P1_eolic_bueno-past_eolic)*(TIME-2010)/10,P1_eolic_bueno) IF(TIME<2015,past_eolic+(P1_eolic-past_eolic)*(TIME-2010)/5,P1_eolic)

aux Adapt_a_Etransp = IF(TIME<2009,Historical_a_Transp_Intensity,IF(TIME<2016,0.9932979819,IF(TIME<2021,0.9932979819+(a_Etransp_intensity_evolution_2015-0.993)*(TIME-2016)/5,a_Etransp_intensity_evolution_2015)))

doc Adapt_a_Etransp = IF(TIME<2020,past_eolic+(P1_eolic_bueno-past_eolic)*(TIME-2010)/10,P1_eolic_bueno) IF(TIME<2015,past_eolic+(P1_eolic-past_eolic)*(TIME-2010)/5,P1_eolic)

aux Adapt_emissions_unconv_gas = IF(TIME<2050,0.01+(0.22-0.01)*(TIME-2000)/50,IF(TIME<2100,0.22+(0.60-0.15)*(TIME-2050)/50,0.60))

doc Adapt_emissions_unconv_gas = IF(TIME<2050,0.01+(0.22-0.01)*(TIME-2000)/50,IF(TIME<2100,0.22+(0.60-0.15)*(TIME-2050)/50,0.60)) Tomando la proporción de shale oil respecto de [Mohr&Evans2011] para 2050 y 2100 del BG.

aux Adapt_emissions_unconv_oil = IF(TIME<2050,0.001+(0.15-0.001)*(TIME-2000)/50,IF(TIME<2100,0.15+(0.72-0.15)*(TIME-2050)/50,0.72))

doc Adapt_emissions_unconv_oil = Tomando la proporción de shale oil respecto de [Mohr&Evans2010] para 2050 y 2100 del Low Case.

aux Adapt_growth_BioW = IF(TIME<2015,past_BioW+(P1_BioW-past_BioW)*(TIME-2010)/5,P1_BioW)

doc Adapt_growth_BioW = IF(TIME<2020,past_eolic+(P1_eolic_bueno-past_eolic)*(TIME-2010)/10,P1_eolic_bueno)

aux Adapt_growth_geot = IF(TIME<2015,past_geot+(P1_geot-past_geot)*(TIME-2010)/5,P1_geot)

doc Adapt_growth_geot = IF(TIME<2020,past_eolic+(P1_eolic_bueno-past_eolic)*(TIME-2010)/10,P1_eolic_bueno)

aux Adapt_growth_hydro = IF(TIME<2015,past_hydro+(P1_hydro-past_hydro)*(TIME-2010)/5,P1_hydro)

doc Adapt_growth_hydro = IF(TIME<2020,past_eolic+(P1_eolic_bueno-past_eolic)*(TIME-2010)/10,P1_eolic_bueno) IF(TIME<2015,past_eolic+(P1_eolic-past_eolic)*(TIME-2010)/5,P1_eolic)

aux Adapt_growth_oceanic = IF(TIME<2015,past_oceanic+(P1_oceanic-past_oceanic)*(TIME-2010)/5,P1_oceanic)

aux Adapt_growth_solar = IF(TIME<2015,past_solar+(P1_solar-past_solar)*(TIME-2010)/5,P1_solar)

doc Adapt_growth_solar = IF(TIME<2020,past_eolic+(P1_eolic_bueno-past_eolic)*(TIME-2010)/10,P1_eolic_bueno)

aux Adapt_growth_wind = IF(TIME<2015,past_wind+(P1_wind-past_wind)*(TIME-2010)/5,P1_wind)

aux add_losses_GTL_CTL_EJ = (1-GTL_efficiency)*demand_gas_GTL_EJ+(1-CTL_efficiency)*demand_coal_CTL_EJ

aux Afforestation_program_2020 = GRAPH(TIME,2020,5,[0,138.2727,299.5604,452.9353,597.8799,733.8764,860.4075,976.9556,1083.003,1178.033,1261.526,1332.967,1391.836,1437.618,1469.794,1487.846,1491.257,1479.51,1452.086,1408.47,1348.141"Min:0;Max:1"])

doc Afforestation_program_2020 = Following [Nilsson1995], from 2020 (time to inverse the deforestation trend).

aux anual_emissions_coal_carlos = 0.0165*(extraction_coal_EJ)

aux anual_emissions_gas_carlos = 0.0165*(extraction_gas_EJ)

doc anual_emissions_gas_carlos = ton CO2 / GJ

aux anual_emissions_GtCe_Castro_II = GRAPH(TIME,1985,1,[6.097364,6.265805,6.431147,6.593531,6.753097,6.90997,7.064236,7.215932,7.365029,7.511421,7.654915,7.79523,7.931991,8.064733,8.192911,8.315912,8.433069,8.543686,8.647061,8.742512,8.829409,8.909383,8.98165,9.046083,9.102679,9.151575,9.193048,9.227519,9.255547,9.27781,9.295088,9.303602,9.287788,9.24653,9.178644,9.085261,8.969607,8.836579,8.692193,8.542961,8.395289,8.256035,8.129607,8.019358,7.927364,7.85444,7.800288,7.763714,7.742877,7.735539,7.739306,7.741788,7.739767,7.73036,7.711909,7.683793,7.64619,7.59984,7.545824,7.48537,7.419712,7.349991,7.277198,7.202152,7.125497,7.017482,6.89654,6.779075,6.667118,6.560961,6.460009,6.363294,6.269754,6.17838,6.088276,5.998682,5.908969,5.818635,5.727289,5.63464,5.540487,5.444709,5.347256,5.248137,5.147419,5.045213,4.94167,4.836977,4.731697,4.631635,4.538658,4.452208,4.3715

54,4.295954,4.224714,4.157206,4.092869,4.031203,3.971764,3.914156,3.858029,3.803071,3.749005,3.695589,3.642612,3.589888,3.537262,3.484603,3.431803,3.378777,3.325461,3.271811,3.217801,3.163422,3.108681,3.053597"Min:0;Max:1"])

aux anual_emissions_GtCe_Castro_madcoal = GRAPH(TIME,1985,1,[6.070026,6.21033,6.347372,6.481814,6.614401,6.745928,6.877195,7.008978,7.141994,7.27687,7.414115,7.554102,7.697051,7.843014,7.991873,8.143337,8.29695,8.452097,8.608031,8.763884,8.918708,9.073199,9.225984,9.376152,9.522845,9.66529,9.802839,9.934997,10.06145,10.18206,10.29689,10.40119,10.47893,10.53011,10.55412,10.55241,10.5281,10.48547,10.42945,10.36509,10.29715,10.23061,10.16846,10.11305,10.06595,10.028,9.99942,9.979992,9.969153,9.966143,9.970103,9.96982,9.964574,9.953268,9.935472,9.911189,9.880671,9.844292,9.802455,9.755538,9.70386,9.647664,9.58711,9.522283,9.453194,9.353327,9.241047,9.127749,9.014263,8.900445,8.785727,8.669403,8.550781,8.429253,8.304322,8.175614,8.042876,7.905968,7.764854,7.619598,7.470348,7.317327,7.160826,7.001191,6.838812,6.674118,6.507561,6.339613,6.171038,6.006726,5.848283,5.695409,5.547682,5.404662,5.265934,5.131119,4.999874,4.871894,4.746905,4.624665,4.504957,4.387591,4.272401,4.15924,4.047984,3.938526,3.830779,3.724671,3.620147,3.517164,3.415696,3.315725,3.217248,3.120269,3.024801,2.930866"Min:0;Max:1"])

aux anual_emissions_oil_carlos = 0.0165*(extraction_crude_oil_EJ)

doc anual_emissions_oil_carlos = 0.0165 ton CO2 / GJ

aux Auxiliary_5 = IF(extraction_uranium_EJ-demand_uranium_EJ<0,0,1)

doc Auxiliary_5 = IF(extraction_uranium_EJ-demand_uranium_EJ<0,0,1). Si la demanda de energía nuclear es mayor que lo que se puede extraer, entonces esta variable se pone a 0, y entonces no deja que se cree más "new_nuclear_TWe".

aux available_BioE_Heat_EJ = BioE_residues*BioE_to_heat

aux B1 = GRAPH(TIME,1990,10,[21.96754,25.28659,30.27517,33.68105,36.39605,36.33466,33.87112,30.65859,26.84704,23.32632,19.20034,17.17003"Min:0;Max:1"])

aux B2 = GRAPH(TIME,1990,10,[21.96754,25.28659,29.29307,33.0649,37.21437,40.0763,41.19371,43.03057,43.52739,45.69802,48.39502,50.68861"Min:0;Max:1"])

aux balancing_cost = GRAPH(proportion_E_var_base_percent,0,10,[0,2.8,4.2,5.6,6.3,7,7,7,7,7,7"Min:0;Max:10"])/1000000

doc balancing_cost = Cost adapting data from [Holttinen2011]. 2011 T$ / TWh produced

aux bioLiquid_saved_by_bio_Mtoe = Oil_saved_by_bio_EJ*(1000/41.868)

aux BioLiquids_available_EJ = (primary_BioE_2a_gen_EJ+BioE_3a_gen_EJ)

doc BioLiquids_available_EJ = de [Triana2011] para Brasil (optimista para todo el mundo)

aux Biomass = (Trad_biomass_Mtoe_2+biomass_production_E_Mtoe_2)

aux biomass_emissions = ((2.35*Biofuels_liquid_saved_for_bio_Mtoe+0*Biomass)/1000)

doc biomass_emissions = [GtC] A los biofuels les ponemos como el gas natural, y al resto de biomasa nada.

aux BioW_Primary_Mtoe = E_BioW_Primary_EJ*(1000/41.868) doc BioW_Primary_Mtoe = Conversión de la producción eléctrica a Mtoe

aux C_sent_to_atmosphere_GtC = (3/11)*CO2_production_GtCO2

doc C_sent_to_atmosphere_GtC = [Gt C] 3/11 de la estequimetria del CO2, equivalente a la fracción: 12/(12+16+16)

aux cir_coal_production_EJ = extraction_coal_EJ*propor_cir_coal

aux CIR_comprob_Mtoe = (demand_coal_I_EJ_1+demand_coal_RC_EJ_1+demand_gas_I_EJ_1+demand_gas_RC_EJ_1+demand_liquids_I_1+demand_liquids_RC_1+I_renew_1+RC_renew_1)*(1000/41.868)

aux CIR_E_demand_after_policies = I_after_efficiency_EJ+RC_after_efficiency_EJ

aux CIR_EJ = dem_Ecir_prim_E_EJ

aux CIR_energy_extraction_EJ = cir_coal_production_EJ+cir_gas_production_EJ+cir_liquids_production_EJ+Renew_non_elec_CIR_EJ

aux cir_gas_production_EJ = extraction_gas_EJ*propor_cir_gas

aux cir_liquids_production_EJ = (Total_demand_Liquids_EJ-Total_demand_OIL_EJ+extraction_crude_oil_EJ)*propor_cir_liquids

aux CIR_renew_savings_EJ = I_renew_efficiency+RC_renew_efficiency

doc CIR_renew_savings_EJ = Considerando que por 1 EJ de energía primaria sustituido CIR por las renovables: 1/2 es sustitución pura y el otro 1/2 se ahorra (se reduce la demanda efectiva).

aux CO2_production_GtCO2 = fossil_emissions_GtCO2+biomass_emissions+electric_renewables_emissions+nuclear_emissions-Afforestation_program_2020*(11/3)*0/1000

doc CO2_production_GtCO2 = Gt CO2

aux CO2ppm_test = (1/7.8)*CO2_production_GtCO2

aux Coal_Castro_I = GRAPH(TIME,1985,1,[1945.628,1995.964,2045.029,2092.891,2139.617,2185.277,2229.928,2273.615,2316.365,2358.188,2399.064,2438.956,2477.797,2515.499,2551.951,2587.027,2620.584,2652.477,2682.561,2710.696,2736.761,2760.656,2782.311,2801.695,2818.816,2833.727,2846.525,2857.352,2866.392,2873.86,2880.007,2883.66,2879.937,2868.351,2848.329,2819.953,2783.908,2741.381,2693.923,2643.288,2591.28,2540,2490.871,2445.109,2403.651,2367.127,2335.895,2310.077,2289.608,2274.285,2263.82,2256.019,2250.219,2245.761,2242.157,2239.073,2236.323,2233.837,2231.647,2229.859,2228.631,2225.631,2222.309,2219.12,2216.461,2205.259,2186.648,2168.017,2151.253,2137.539,2127.505,2121.376,2119.091,2120.413,2125.007,2132.483,2142.444,2154.501,2168.285,2183.453,2199.688,2216.697,2234.213,2251.987,2269.781,2287.381,2304.577,2321.177,2336.997,2351.864,2365.62,2378.117,2389.221,2398.816,2406.796,2413.076,2417.584,2420.268,2421.089,2420.028,2417.08,2412.253,2405.576,2397.081,2386.823,2374.859,2361.26,2346.107,2329.484,2311.485,2292.208,2271.753,2250.225,2227.729,2204.373,2180.261"Min:0;Max:1"])

aux Coal_Castro_II_Mtoe = GRAPH(TIME,1985,1,[2081.439,2135.515,2188.272,2239.783,2290.124,2339.367,2387.577,2434.807,2481.085,2526.427,2570.816,2614.211,2656.545,2697.728,2737.644,2776.159,2813.123,2848.385,2881.788,2913.185,2942.425,2

970.135,2996.14,3020.472,3043.203,3064.445,3084.363,3103.156,3121.077,3138.412,3155.488,3171.113,3180.04,3181.728,3175.592,3161.797,3141.211,3115.284,3085.905,3055.197,3025.335,2998.716,2977.043,2961.66,2953.524,2953.177,2960.781,2976.172,2998.939,3028.5,3064.183,3101.34,3138.559,3174.511,3208.264,3239.241,3267.141,3291.871,3313.465,3332.031,3347.679,3360.497,3370.532,3377.769,3382.148,3369.608,3346.488,3321.229,3294.992,3268.097,3240.417,3211.631,3181.371,3149.303,3115.165,3078.779,3040.045,2998.944,2955.516,2909.855,2862.099,2812.419,2761.007,2708.073,2653.84,2598.532,2542.372,2485.583,2428.504,2374.077,2323.461,2276.451,2232.715,2191.899,2153.665,2117.705,2083.74,2051.52,2020.821,1991.447,1963.215,1935.965,1909.555,1883.853,1858.745,1834.127,1809.908,1786.007,1762.351,1738.881,1715.543,1692.293,1669.093,1645.913,1622.732,1599.532"Min:0;Max:1"])

aux Coal_Castro_III = GRAPH(TIME,1985,1,[1945.628,1995.964,2045.029,2092.891,2139.617,2185.277,2229.928,2273.615,2316.365,2358.188,2399.064,2438.956,2477.797,2515.499,2551.951,2587.027,2620.584,2652.477,2682.561,2710.696,2736.761,2760.656,2782.311,2801.695,2818.816,2833.727,2846.525,2857.313,2865.651,2871.104,2873.467,2871.231,2859.315,2837.161,2804.26,2760.865,2707.913,2646.88,2579.6,2508.073,2434.288,2360.072,2286.979,2216.233,2148.709,2084.941,2025.172,1969.391,1917.401,1868.877,1823.408,1779.848,1737.753,1696.691,1656.32,1616.383,1576.689,1537.111,1497.563,1458.001,1418.407,1378.781,1339.14,1299.507,1259.907,1215.026,1164.711,1113.385,1062.051,1011.369,961.7467,913.4087,866.46,820.9301,776.8051,734.0513,692.6299,652.5057,613.6525,576.0543,539.7056,504.6109,470.782,438.236,406.9939,377.0771,348.5065,321.2999,295.4708,271.0269,247.9695,226.2921,205.9811,187.0149,169.3649,152.9952,137.864,123.9239,111.1229,99.40564,88.71399,78.98808,70.16719,62.19049,54.99783,48.53019,42.73033,37.54315,32.91596,28.79883,25.14464,21.90927,19.05156,16.53339,14.31955,12.37769"Min:0;Max:1"])

aux Coal_Castro_madcoal = GRAPH(TIME,1985,1,[2058.92,2092.273,2125.719,2159.473,2193.76,2228.812,2264.86,2302.131,2340.839,2381.181,2423.341,2467.472,2513.705,2562.145,2612.867,2665.915,2721.307,2779.032,2839.057,2901.327,2965.741,3032.573,3101.673,3172.972,3246.4,3321.899,3399.425,3478.961,3560.513,3644.12,3729.857,3816.115,3897.753,3974.808,4046.619,4112.968,4174.055,4230.437,4282.941,4332.571,4380.4,4427.687,4475.376,4524.248,4574.935,4627.892,4683.411,4741.629,4802.568,4866.149,4932.233,4997.041,5059.895,5120.048,5176.957,5230.208,5279.471,5324.457,5364.899,5400.523,5431.048,5456.18,5475.613,5489.039,5496.155,5485.533,5462.411,5433.003,5397.992,5357.583,5311.761,5260.447,5203.567,5141.105,5073.113,4999.716,4921.113,4837.565,4749.388,4656.947,4560.64,4460.897,4358.163,4252.895,4145.552,4036.593,3926.465,3815.603,3704.469,3595.324,3489.224,3386.159,3286.012,3188.632,3093.869,3001.58,2911.633,2823.912,2738.311,2654.736,2573.108,2493.352,2415.405,2339.215,2264.732,2191.917,2120.736,2051.16,1983.165,1916.732,1851.845,1788.493,1726.664,1666.349,1607.541,1550.236"Min:0;Max:1"])

aux compr_100 = propor_RC_coal+propor_RC_gas+propor_RC_liquids+propor_RC_renew

aux Compr_100_I = propor_i_coal+propor_i_gas+propor_i_liquids+propor_i_renew

aux consum_average_CV = 0.07*km_yr_average_car

doc consum_average_CV = Israel toma 0,08 litros/km para gasolina y 0,06 para diesel, tomo 0,07 l/km porque el numero de coches de gasolina es un 53% (en España al menos). Y el numero de km al año Israel toma 20 000 (dato España, PPP toma 13000 para el mundo?¿). Esto da entre 1400 y 930, bastante diferencia!

aux copper_on_cars = 20*number_of_EV_on_the_road

doc copper_on_cars = 20Kg de cobre por vehiculo electrico segun 4.1 PPP

aux copper_production = 20*production_EV doc copper_production = ^20Kg de cobre por coche segun PPP 4.1

aux cost_energy_bioW = new_BioW_TWe*8760*(life_time_BioW/TRE_bioW)

doc cost_energy_bioW = Necesidades energéticas para llevar a cabo las nuevas instalaciones.

aux cost_energy_geot = new_geot_TWe*8760*(life_time_geot/TRE_geot)

doc cost_energy_geot = Necesidades energéticas para llevar a cabo las nuevas instalaciones.

aux cost_energy_hydro = new_hydro_TWe*8760*(life_time_hydro/TRE_hydro)

doc cost_energy_hydro = Necesidades energéticas para llevar a cabo las nuevas instalaciones.

aux cost_energy_oceanic = new_oceanic_TWe*8760*(life_time_oceanic/TRE_oceanic)

doc cost_energy_oceanic = Necesidades energéticas para llevar a cabo las nuevas instalaciones.

aux cost_energy_renew_EJ = cost_energy_renew_TWh*(3.6/1000)

aux cost_energy_renew_TWh = cost_energy_biomass_2+cost_energy_eolic_2+cost_energy_geot_2+cost_energy_hydro_2+cost_energy_oceanic_2+ cost_energy_solar_2

aux cost_energy_solar = new_solar_TWe*8760*life_time_solar/TRE_solar

doc cost_energy_solar = Necesidades energéticas para llevar a cabo las nuevas instalaciones.

aux cost_energy_wind = new_wind_TWe*8760*life_time_wind/TRE_wind

doc cost_energy_wind = Necesidades energéticas para llevar a cabo las nuevas instalaciones.

aux crude_oil_Transp_EJ = extraction_crude_oil_EJ*propor_Transp_liquids

aux CTL_and_GTL_EJ = CTL_EJ+GTL_EJ

aux CTL_and_GTL_Gb = CTL_and_GTL_EJ*(1/5.582)

aux CTL_and_GTL_Mtoe = CTL_Mtoe+GTL_Mtoe

aux CTL_Gb = CTL_EJ*(1/5.582)

aux CTL_Mtoe = CTL_EJ*(1000/41.868)

aux delivered_BioE_Electricity_TWe = delivered_BioE_Electricity_EJ_1*1000/(3.6*8760)

aux dem_CIR_after_policies_EJ = CIR_E_demand_after_policies

aux Dem_CIR_EJ_without_trad_biomass_2 = CIR_EJ

aux dem_E_coal_TWh = demand_coal_E_EJ*(1000/3.6)*efficiency_coal

doc dem_E_coal_TWh = Producción eléctrica en TWh procedente del carbón.

aux dem_E_gas_TWh = demand_gas_E_EJ*(1000/3.6)*efficiency_gas

doc dem_E_gas_TWh = Producción eléctrica en TWh procedente del gas natural.

aux dem_E_oil_TWh = demand_oil_E_EJ*(1000/3.6)*efficiency_oil doc dem_E_oil_TWh = Demanda de TWh de petróleo para satisfacer su parte en la electricidad producida.

aux Dem_E_TWh_delayed_1yr = DELAYINF(Dem_Elec_consum_TWh, 1,1,11057)

doc Dem_E_TWh_delayed_1yr = In 1989 electric energy generated was 11057 TWh.

aux dem_Ecir_prim_E_EJ = Ecir_Intensity*GDP_S2011

doc dem_Ecir_prim_E_EJ = Demanda primaria de energía total (EJ)

aux dem_Eind_prim_EJ_delayed_1yr = DELAYINF(dem_Ecir_prim_E_EJ,1,1,140)

doc dem_Eind_prim_EJ_delayed_1yr = Como el modelo empieza a correr en 1990, tomo el valor 1 años antes, es decir de 1989: 96.60036168 EJ.

aux Dem_Elec_consum_EJ = Dem_Elec_consum_TWh*(3.6/1000)

aux Dem_Elec_consum_TWh = (GDP_S2011*Eelec_consum_Intensity)

doc Dem_Elec_consum_TWh = Demanda total de energía eléctrica consumida (TWh)

aux Dem_Elec_gen_EJ = Dem_Elec_gen_TWh*(3.6/1000)

doc Dem_Elec_gen_EJ = Demanda eléctrica en EJ.

aux Dem_Elec_gen_Mtoe = Dem_Elec_gen_EJ*(1000/41.868)

aux Dem_Elec_gen_TWe = Dem_Elec_gen_TWh/8760

doc Dem_Elec_gen_TWe = Demanda eléctrica en TWe.

aux Dem_Elec_gen_TWh = (Dem_Elec_consum_TWh+Increase_Elec_total_TWh_1)*(1+Propr_electrical_distribution_losses)

doc Dem_Elec_gen_TWh = Demanda anual de energía eléctrica (TWh). Añadimos el incremento debido a la transición de petróleo a electricidad (transporte "eléctrico" de personas y mercancías - coche eléctrico, potenciación del tren...). Añadimos además las pérdidas por transporte que son de alrededor del 9% (5.15).

aux dem_liquids_EJ = Total_demand_Liquids_EJ+BioLiquids_available_EJ

aux dem_Nuclear_TWh = IF(TIME<2012,historic_TWh_nuclear,MAX(dem_Nuclear_TWh_1,0))

doc dem_Nuclear_TWh = [TWh] producidos en 2005 y 2006. Según 9.1 el escenario más optimista para la industria nuclear a corto plazo es el de mantener la energía producida actualmente (año 2007).

aux dem_Nuclear_TWh_1 = IF(P_nuclear_scen_4>0,dem_Nuclear_TWh_scen4,dem_Nuclear_TWh_scen1_2_3)

aux dem_Nuclear_TWh_scen1_2_3 = IF(P_nuclear_scen_1<1,2507,Nuclear_power_GW*(2507/374))

doc dem_Nuclear_TWh_scen1_2_3 = Energía producida constante.

aux dem_Nuclear_TWh_scen4 = Nuclear_TWe*8760

aux dem_Prim_E_after_policies_EJ = dem_Prim_E_Mtoe_after_policies*(41.868/1000) aux dem_Prim_E_Mtoe_after_policies = (1000/41.868)*(I_after_efficiency_EJ+RC_after_efficiency_EJ+Dem_Transport_after_policies_EJ+Dem_Elec_gen_EJ+Dem_traditional_Biomass_EJ_1+add_losses_GTL_CTL_EJ)+E_gen_related_losses_Mtoe_2

doc dem_Prim_E_Mtoe_after_policies = (1000/41.868)*(dem_Industrial_after_savings+dem_RC_after_savings+dem_transport_after_politics_EJ+Dem_Elec_EJ+Dem_traditional_Biomass_EJ_1)+E_related_losses_Mtoe_1

aux Dem_Transport_after_policies_EJ = demand_gas_transport_EJ+E_total_Transp_EJ+real_Oil_Transport_demand_EJ+Oil_saved_by_bio_EJ

aux Dem_Transport_after_policies_Mtoe = Dem_Transport_after_policies_EJ*(1000/41.868)

aux Dem_Transport_initial_EJ = (Etransp_intensity*GDP_S2011)

doc Dem_Transport_initial_EJ = [EJ] Curva de demanda de energía primaria para Transporte anual sacada de [4.18] con datos de 1991 a 2005 (tenemos datos desde 1971, pero se observan algunos cambios de pendiente, nos quedamos con la última tendencia). La correlamos con el GDP (T$) no PPP en dolares constantes 2000 sacado del BM datos de Julio.

aux Dem_Transport_initial_EJ_delayed_1yr = DELAYINF(Dem_Transport_initial_EJ,1,1,66.88)

doc Dem_Transport_initial_EJ_delayed_1yr = Retraso de un año, y pongo la energía primaria para transporte del año 1989: 66.88 EJ.

aux Dem_Transport_initial_Mtoe = Dem_Transport_initial_EJ*(1000/41.868)

aux demand_coal_CTL_EJ = CTL_EJ/CTL_efficiency

aux demand_coal_E_EJ = propor_coal_E*(demand_E_nr_except_nuclear_TWh/efficiency_coal)*(3.6/1000)

doc demand_coal_E_EJ = Demanda de EJ de carbón para satisfacer su parte en la electricidad producida.

aux demand_coal_para_E_Mtoe = demand_coal_para_E_EJ_1*(1000/41.868)

aux demand_E_nr_except_nuclear_TWh = MAX(0,Demand_E_nr_TWh-nuclear_priority)

doc demand_E_nr_except_nuclear_TWh = Dentro de la generación no renovable, damos prioridad a la de origen nuclear por sus características.

aux Demand_E_nr_TWh = MAX(0,(Dem_Elec_gen_TWh-E_renew_TWh))

doc Demand_E_nr_TWh = Demanda eléctrica (E) no renovable (nr): damos prioridad a la electricidad producida mediante fuentes renovables, el resto de la demanda se cubre con no renovables.

aux demand_E_transport_E = Dem_Transport_initial_EJ*propor_E

doc demand_E_transport_E = (está ya incluido en la parte eléctrica del modelo)

aux demand_gas_E_EJ = propor_gas_E*(demand_E_nr_except_nuclear_TWh/efficiency_gas)*(3.6/1000)

doc demand_gas_E_EJ = Demanda de EJ de gas natural para satisfacer su parte en la electricidad producida.

aux demand_gas_GTL_EJ = GTL_EJ/GTL_efficiency

aux demand_gas_para_E_Mtoe = demand_gas_E_EJ*(1000/41.868) aux demand_gas_transport_EJ = liquid_saved_NGV*1.15+Dem_Transport_initial_EJ*propor_gas_losses

doc demand_gas_transport_EJ = Parte de la demanda del sector transporte cubierta por Gas Natural. Due to the transformation processes and associated losses, the gas consumed is 85% of the gas extracted (Kleine&NagerlVoot 2012).

aux demand_oil_E_EJ = propor_oil_E*(demand_E_nr_except_nuclear_TWh/efficiency_oil)*(3.6/1000)

doc demand_oil_E_EJ = Producción eléctrica en TWh procedente del petróleo.

aux demand_uranium_EJ = nuclear_priority*(3.6/1000)*(1/efficiency_nuclear)

doc demand_uranium_EJ = Demanda eléctrica cubierta por la energía nuclear.

aux E_BioW_Primary_EJ = E_BioW_production_TWh*(3.6/1000)*(1/0.22)

doc E_BioW_Primary_EJ = Conversión a EJ

aux E_BioW_production_TWh = BioW_TWe*8760

aux E_coal_production_historic = GRAPH(TIME,1990,1,[4418.177,4524.84,4605.761,4709.099,4843.804,4985.231,5222.524,5341.864,5451.172,5577.501,5992.855,6007.93,6293.1,6714.027,6931.621,7325.109,7745.171,8217.528,8296.291,8145.237,8685.121"Min:0;Max:1"])

doc E_coal_production_historic = Data extracted from World Bank database: "Electricity production from coal sources (kWh)"

aux E_coal_production_TWh = extraction_coal_EJ*propor_E_coal*(1000/3.6)*efficiency_coal_1

aux E_gas_production_historic = GRAPH(TIME,1990,1,[1727.089,1756.264,1772.987,1825.592,1900.401,2002.018,2072.437,2225.039,2360.597,2562.396,2730.407,2883.331,3082.948,3240.486,3487.112,3661.517,3844.982,4170.43,4332.051,4366.547,4763.679"Min:0;Max:1"])

aux E_gas_production_TWh = extraction_gas_EJ*propor_E_gas*(1000/3.6)*efficiency_gas_1

aux E_gen_related_losses_EJ = E_gen_related_losses_Mtoe*(41.868/1000)

aux E_gen_related_losses_EJ_1 = DELAYINF(E_gen_related_losses_EJ,1,1,77.456)

aux E_gen_related_losses_EJ_3 = E_gen_related_losses_EJ

aux E_gen_related_losses_Mtoe = E_losses_coal_Mtoe_1+E_losses_gas_Mtoe_1+E_losses_oil_Mtoe_1+E_losses_nuclear_Mtoe_1

aux E_gen_related_losses_Mtoe_1 = DELAYINF(E_gen_related_losses_Mtoe,1,1,1750)

aux E_gen_related_losses_Mtoe_2 = E_gen_related_losses_EJ_3*1000/41.868

aux E_geot_production_EJ = E_geot_production_TWh*(3.6/1000)*3

doc E_geot_production_EJ = Conversión a EJ

aux E_geot_production_TWh = geot_TWe*8760

aux E_hydro_production_EJ = E_hydro_production_TWh*(3.6/1000) doc E_hydro_production_EJ = Conversión a EJ

aux E_hydro_production_TWh = hydro_TWe*8760

doc E_hydro_production_TWh = [WEO2012]: En 2010 había 3400 TWh de hydro.

aux E_intensity_EJ_TS = E_Intensity_Mtoe_TS*0.041868

aux E_Intensity_Mtoe_TS = extraction_total_Mtoe/GDP_2

doc E_Intensity_Mtoe_TS = Intensidad energética mundial.

aux E_losses_coal_EJ = E_losses_coal_Mtoe*(41.868/1000)

aux E_losses_coal_Mtoe = extraction_coal_Mtoe*propor_E_coal*(1-efficiency_coal_1)

aux E_losses_coal_Mtoe_1 = E_losses_coal_Mtoe

aux E_losses_gas_Mtoe = extraction_gas_Mtoe*propor_E_gas*(1-efficiency_gas_1)

aux E_losses_nuclear_Mtoe = extraction_uranium_Mtoe*(1-1/3)

aux E_losses_oil_Mtoe = extraction_crude_oil_Mtoe*propor_E_liquids*(1-1/3)

aux E_losses_TranspElec = (Increase_Elec_total_TWh_1*(3.6/1000)/Dem_Elec_gen_EJ)*E_gen_related_losses_EJ_2

aux E_nr = nonRenew_E_TWh_production

aux E_Nuclear_TWh_production = extraction_uranium_EJ*(1000/3.6)*efficiency_nuclear

aux E_oceanic_production_EJ = E_oceanic_production_TWh*(3.6/1000)

doc E_oceanic_production_EJ = Conversión a EJ

aux E_oceanic_production_TWh = IF(TIME<2007,0,oceanic_TWe*8760)

aux E_oil_production_TWh = extraction_crude_oil_EJ*propor_E_liquids*(1000/3.6)*efficiency_oil

aux E_pc = E_TWh2/(Population_1*2.21e-6)

aux E_renew_production_historic = GRAPH(TIME,1990,1,[2289.793,2327.817,2340.134,2474.379,2501.589,2627.329,2665.059,2705.988,2725.882,2747.814,2827.548,2775.432,2867.959,2903.702,3111.836,3274.082,3422.739,3517.28,3706.478,3846.077,4137.351"Min:0;Max:1"])

doc E_renew_production_historic = Data extracted from World Bank database: "Electricity production from coal sources (kWh)"

aux E_renew_TWh = solar_production_TWh_2+bioW_production_TWh_2+wind_production_TWh_2+geot_production_TWh_2+hydro_production_TWh_2+oceanic_production_TWh_2

doc E_renew_TWh = MIN(demand_E_TWh,hydro_production_TWh_2+eolic_production_TWh_2+biomass_production_TWh_2+geot_production_TWh_2+oceanic_production_TWh_2+solar_production_TWh_2) aux E_renew_TWh_1 = biomasa_production_TWh_2+ewind_production_TWh_3+Geot_production_TWh_3+hydro_production_TWh_3+oceanic_production_TWh_3+solar_production_TWh_3

doc E_renew_TWh_1 = Total de electricidad generada renovable

aux E_renew_TWh_EJ = E_renew_TWh*(3.6/1000)

doc E_renew_TWh_EJ = Conversión a EJ

aux E_solar_production_EJ = E_solar_production_TWh*(3.6/1000)

doc E_solar_production_EJ = Conversión a EJ

aux E_solar_production_TWh = solar_TWe*8760

aux E_total_Transp_EJ = E_losses_TranspElec+Increase_E_total_EJ+demand_E_transport_E

doc E_total_Transp_EJ = Transporte eléctrico (1%: tren) + coche eléctrico (EJ útiles) + pérdidas asociadas a la producción de energía para coche eléctrico

aux E_wind_production_EJ = E_wind_production_TWh*(3.6/1000)

doc E_wind_production_EJ = Conversión a EJ

aux E_wind_production_TWh = wind_TWe*8760

aux Ecir_Intensity = IF(TIME<2008,Historical_a_cir_E_intensity*Ecir_Intensity_delayed_1yr,Icir_min+(Icir_2007-Icir_min)*Adapt_a_Ecir^t_Icir)

doc Ecir_Intensity = Esta es la fórmula de la intensidad energética total: I(t)=a*I(t-1)

aux Ecir_Intensity_delayed_1yr = dem_Eind_prim_EJ_delayed_1yr/GDP_delayed_1yr

aux Eelec_consum_Intensity = IF(TIME<2011,a_Historical_Elec_intensit*Eelec_consum_intensity_delayed_1yr,Ielec_min+(Ielec0_2010-Ielec_min)*Adapt_a_Eelec^t_elec)

doc Eelec_consum_Intensity = TWh consumidos / 2011T$

aux Eelec_consum_intensity_delayed_1yr = Dem_E_TWh_delayed_1yr/GDP_delayed_1yr

aux efficiency_coal = IF(TIME<2030,-2.3634E-05*TIME^2 + 9.7020E-02*TIME - 9.9178E+01 ,0.38)

doc efficiency_coal = IF(TIME<2030,-2.3634E-05*TIME^2 + 9.7020E-02*TIME - 9.9178E+01 ,0.38)Eficiencia (mundial) de las centrales de carbón. Por defecto se suele aplicar 1/3, sin embargo en 5.13 obtenemos datos de la eficiencia de 2006 (34 %) y su evolución a 2030 (38 %). Antes del 2006 la dejamos en 34%, y después del 2030 en el 38%.

aux efficiency_gas = IF(TIME<2050,-0.00001587*TIME^2 + 0.06679365*TIME - 69.72063492,0.5)

doc efficiency_gas = Eficiencia (mundial) de las centrales de gas. De momento pongo 1/2 porque tengo dificultades para calcular la exacta. Según WEO 2010 - 3, la media mundial es 0.45

aux Electrical_distribution_losses_EJ = Electrical_distribution_losses_Mtoe_1*(41.868/1000)

aux Electrical_distribution_losses_Mtoe = Electrical_distribution_losses_TWh*(3.6/1000)*(1000/41.868) aux Electrical_distribution_losses_Mtoe_1 = Electrical_distribution_losses_Mtoe

aux Electrical_distribution_losses_TWh = Dem_Elec_gen_TWh*Propr_electrical_distribution_losses

aux emissions_cum_Castro_II_Gtce = GRAPH(TIME,1990,10,[0,79.21533,173.2452,272.8075,364.4224,449.1647,530.6436,602.0536,662.7733,712.4617,754.2312,789.975"Min:0;Max:1"])

aux emssions_cum_Castro_madcoal_Gtce = GRAPH(TIME,1990,10,[0,78.51935,173.7556,283.6167,394.364,501.4214,605.4263,699.5309,779.2585,841.9864,890.356,927.2079"Min:0;Max:1"])

aux Etransp_intensity = IF(TIME<2008,Historical_a_Transp_Intensity*Etransp_Intensity_delayed_1yr,IF(TIME<2016,0.9932979819*Etransp_Intensity_delayed_1yr,(Itransp_min+(Itransp_2015-Itransp_min)*Adapt_a_Etransp^t_Iransp)))

doc Etransp_intensity = Si la variable "Select_E_Transp_intensity"=1, entonces estamos empleando la forma I(t)=a*I(t-1), si escribimos cualquier otro valor, entonces emplearemos la forma de [Schenck2007].

aux Etransp_Intensity_delayed_1yr = Dem_Transport_initial_EJ_delayed_1yr/GDP_delayed_1yr

aux extr_Unconv_oil_Mbd = extraction_unconv_oil_EJ*1000/(5.582*365)

doc extr_Unconv_oil_Mbd = *365*5.582/1000

aux extra_invest_variable_renew = E_wind_production_TWh*balancing_cost+new_wind_TWe*1.43

doc extra_invest_variable_renew = Según [Mills et al 2012], tomo la mediana: 300 4/KW instalados = 1.43 T$/TWe. Inversión en desarrollo de redes eléctricas e interconexiones para permitir la producción de renovables variables según 11.4 (entre 1 y 4 euros/MWh, pero al correlar la inversión de REE en España desde 2003 con la eólica me salen 21 euros/MWh). Tomo 21 euros/MWh (1.33T$/TWe).

aux extraction_coal_Mtoe = extraction_coal_EJ*(1000/41.868)

doc extraction_coal_Mtoe = Conversión de la extracción anual de carbón a Mtoe.

aux extraction_coal_Mtoe_1 = extraction_coal_Mtoe

aux extraction_crude_oil_Mtoe = extraction_crude_oil_EJ*(1000/41.868)

doc extraction_crude_oil_Mtoe = Conversión de la extracción de petróleo a Mtoe.

aux extraction_crude_oil_Mtoe_1 = extraction_crude_oil_Mtoe

aux extraction_gas_Mtoe = extraction_gas_EJ*(1000/41.868)

doc extraction_gas_Mtoe = Conversión de la extracción anual de gas natural a Mtoe .

aux extraction_gas_Mtoe_1 = extraction_gas_Mtoe

aux extraction_oil_Gb = extraction_crude_oil_EJ*(1/5.582)

doc extraction_oil_Gb = Conversión de la extracción a Gb anuales

aux extraction_other_liquids_EJ = BioLiquids_available_EJ+Other_liquids_EJ

doc extraction_other_liquids_EJ = Incluye Biofuels, CTL, GTL, Refinery gains, unconventional oil.

aux extraction_total_EJ = extraction_total_Mtoe*(41.868/1000)

aux extraction_total_Mtoe = extraction_coal_Mtoe_1+extraction_gas_Mtoe_1+extraction_crude_oil_Mtoe_1+extraction_unconv_oil_Mtoe_1+extraction_uranium_Mtoe_1+renew_electric_Prim_E_Mtoe_1+renew_non_electric_Mtoe_1

doc extraction_total_Mtoe = Energía primaria total extraída mundial anual.

aux extraction_total_Mtoe_delayed_1yr = DELAYINF(extraction_total_Mtoe, 1,1,8631.2)

doc extraction_total_Mtoe_delayed_1yr = Valor inicial: Energía primaria 3 años atrás, en 1987: 8171 Mtoe.

aux extraction_total_Mtoe_delayed_2yr = DELAYINF(extraction_total_Mtoe_delayed_1yr, 1,1,8463.5)

doc extraction_total_Mtoe_delayed_2yr = Valor inicial: Energía primaria 3 años atrás, en 1987: 8171 Mtoe.

aux extraction_total_Mtoe_delayed_3yr = DELAYINF(extraction_total_Mtoe_delayed_2yr, 1,1,8139.4)

doc extraction_total_Mtoe_delayed_3yr = Valor inicial: Energía primaria 3 años atrás, en 1987: 8171 Mtoe.

aux Extraction_total_oil_EJ = Extraction_total_oil_Mtoe*(41.868/1000)

aux Extraction_total_oil_Mtoe = extraction_crude_oil_Mtoe+extraction_unconv_oil_Mtoe

aux extraction_unconv_oil_Mtoe = extraction_unconv_oil_EJ*(1000/41.868)

doc extraction_unconv_oil_Mtoe = Conversión de la extracción de petróleo a Mtoe.

aux extraction_unconv_oil_Mtoe_1 = extraction_unconv_oil_Mtoe

aux extraction_uranium_Kt = extraction_uranium_EJ*1/0.419

aux extraction_uranium_Mtoe = extraction_uranium_EJ*(1000/41.868)

doc extraction_uranium_Mtoe = Conversión a Mtoe desde EJ

aux fossil_emissions_GtCO2 = (3.96*extraction_coal_Mtoe_1+2.35*extraction_gas_Mtoe_1*((1-Adapt_emissions_unconv_gas)+1.5*Adapt_emissions_unconv_gas)+3.07*extraction_crude_oil_Mtoe_1+extraction_unconv_oil_Mtoe_1*3.07*(2*Adapt_emissions_unconv_oil+1.25*(1-Adapt_emissions_unconv_oil)))/1000+increase_emissions_GTL_CTL_GtCO2

doc fossil_emissions_GtCO2 = [BP2012] y [Farrell and Brandt, 2006] para el oil unconventional

aux Gas_Castro_I = GRAPH(TIME,1985,1,[1378.148,1422.433,1466.367,1509.971,1553.265,1596.271,1638.999,1681.447,1723.601,1765.429,1806.879,1847.872,1888.313,1928.081,1967.036,2005.019,2041.852,2077.355,2111.337,2143.615,2174.009,2202.365,2228.548,2252.451,2274.005,2293.183,2309.996,2324.497,2336.78,2346.972,2355.231,2360.563,2358.931,2349.907,2333.019,2308.363,2276.557,2238.656,2196.021,2150.188,2102.723,2055.415,2009.484,1965.956,1925.604,1888.937,1856.225,1827.532,1802.759,1781.692,1764.045,1748.045,1733.151,1718.828,1704.687,1690.467,1676.02,1661.299,1646.324,1631.172,1615.956,1598.984,1581.356,1563.407,1545.421,1521.061,1491.535,1462.019,1433.787,1407.576,1383.712,1362.231,1342.979,1325.688,1310.034,1295.677,1282.279,1269.524,1257.124,1244.821,1232.387,1219.624,1206.361,1192.453,1177.776,1162.232,1145.742,1128.249,1109.715,1090.121,1069.47,1047.78,1025.089,1001.449,976.9292,951.6111,925.5873,898.9597,871.8369,844.332,816.5603,788.6367,760.6747,732.7835,705.0673,677.6237,650.5427,623.906,597.7871,572.2503,547.3508,523.1355,499.6425,476.9019,454.9361,433.7605"Min:0;Max:1"]) aux Gas_Castro_II_Mtoe = GRAPH(TIME,1985,1,[1511.249,1560.275,1609.001,1657.457,1705.673,1753.673,1801.479,1849.093,1896.511,1943.701,1990.616,2037.18,2083.295,2128.837,2173.66,2217.596,2260.459,2302.055,2342.18,2380.635,2417.181,2452.252,2485.645,2517.305,2547.213,2575.391,2601.895,2626.829,2650.339,2672.605,2693.848,2713.04,2725.689,2731.155,2728.824,2718.755,2701.637,2678.701,2651.577,2622.124,2592.252,2564.017,2538.981,2518.291,2502.755,2492.795,2488.479,2489.568,2495.588,2505.897,2519.757,2533.245,2544.98,2553.748,2558.7,2559.315,2555.332,2546.687,2533.448,2515.757,2493.788,2467.708,2437.673,2403.817,2366.257,2315.779,2256.656,2195.621,2133.791,2071.613,2009.203,1946.536,1883.576,1820.316,1756.812,1693.173,1629.561,1566.168,1503.213,1440.92,1379.515,1319.209,1260.201,1202.663,1146.748,1092.58,1040.257,989.8552,941.4381,895.9943,853.8579,814.7624,778.4065,744.5013,712.7855,683.0284,655.0285,628.6096,603.6181,579.92,557.3977,535.9484,515.4819,495.9187,477.1893,459.2325,441.9945,425.4279,409.4909,394.1471,379.3639,365.1129,351.3688,338.1092,325.3141,312.9659"Min:0;Max:1"])

aux Gas_Castro_III = GRAPH(TIME,1985,1,[1378.148,1422.433,1466.367,1509.971,1553.265,1596.271,1638.999,1681.447,1723.601,1765.429,1806.879,1847.872,1888.313,1928.081,1967.036,2005.019,2041.852,2077.355,2111.337,2143.615,2174.009,2202.365,2228.548,2252.451,2274.005,2293.183,2309.996,2324.465,2336.176,2344.72,2349.881,2350.384,2342.036,2324.363,2296.964,2260.103,2214.635,2161.88,2103.469,2041.168,1976.721,1911.725,1847.533,1785.205,1725.495,1668.868,1615.533,1565.492,1518.589,1474.561,1433.079,1393.24,1354.701,1317.135,1280.29,1243.978,1208.07,1172.48,1137.161,1102.092,1067.272,1032.715,998.4412,964.4756,930.8449,893.6252,852.8172,811.7012,771.0097,731.2109,692.5793,655.2537,619.2837,584.6636,551.358,519.3177,488.4915,458.8313,430.2967,402.8555,376.484,351.166,326.8915,303.6549,281.4543,260.2889,240.1584,221.0615,202.9947,185.9516,169.9223,154.8927,140.8449,127.7563,115.6003,104.3466,93.96115,84.40719,75.64548,67.63489,60.33309,53.697,47.68336,42.24921,37.35235,32.95159,29.00717,25.48097,22.33668,19.53991,17.05835,14.86176,12.92202,11.21308,9.710915,8.393489"Min:0;Max:1"])

aux GDP_delayed_1yr = DELAYINF(GDP_S2011,1,1,39.4350)

doc GDP_delayed_1yr = Como el modelo empieza a correr en 1990, tomo el valor 1 años antes, es decir de 1989: 23.524386 T$ US2011.

aux GDP_delayed_2yr = DELAYINF(GDP_delayed_1yr,1,1,38.0333)

doc GDP_delayed_2yr = Como el modelo empieza a correr en 1990, tomo el valor 2 años antes, es decir de 1988 US$2011.

aux GDP_delayed_3yr = DELAYINF(GDP_delayed_2yr,1,1,36.3853)

doc GDP_delayed_3yr = Como el modelo empieza a correr en 1990, tomo el valor 3 años antes, es decir de 1987 US$2011.

aux GDP_S2011 = GDPcap_projection*Population/1000000000

aux geot_production_Mtoe = E_geot_production_EJ*(1000/41.868)

doc geot_production_Mtoe = Conversión de la producción eléctrica a Mtoe

aux growth_GDP_rate = -1+GDP_S2011/GDP_delayed_1yr aux growth_Historic_GDPcap = GRAPH(TIME,1990,1,[-0.0004,0.0057,0.0026,0.0179,0.0138,0.0191,0.0225,0.0093,0.0193,0.0284,0.004,0.0072,0.015,0.0275,0.0227,0.0277,0.0273,0.0015,-0.0335,0.0315,0.0156"Min:0;Max:0.1"])

doc growth_Historic_GDPcap = T$ PPP 2000/yr del WorldBank.

aux growth_historic_Pop = GRAPH(TIME,1990,1,[0.01639,0.01535,0.01523,0.01481,0.01486,0.01426,0.01411,0.01377,0.01337,0.01316,0.01267,0.01239,0.01223,0.01211,0.012,0.0119,0.01184,0.01182,0.01168,0.01152,0.01151"Min:0;Max:1"])

doc growth_historic_Pop = Datos históricos extraídos de World Bank - UN.

aux growth_MEA_AdapMos = GRAPH(TIME,2011,1,[0.016267,0.015683,0.015282,0.014738,0.015606,0.01567,0.016028,0.016217,0.016393,0.016985,0.017123,0.017387,0.017496,0.017862,0.018465,0.018645,0.018808,0.018957,0.019334,0.019325,0.019427,0.01963,0.01959,0.019876,0.019922,0.019851,0.019985,0.020104,0.020008,0.020694,0.020659,0.020712,0.02066,0.020694,0.021248,0.021153,0.021139,0.021034,0.021089,0.021372,0.021315,0.021252,0.021035,0.020968,0.02104,0.020817,0.020599,0.020319,0.020112,0.019975,0.019711,0.019455,0.019206,0.018964,0.0192,0.019012,0.018771,0.018536,0.018308,0.018623,0.018388,0.018263,0.018088,0.017916,0.017699,0.017584,0.017422,0.01731,0.017152,0.017583,0.017367,0.017288,0.017079,0.016961,0.017503,0.017405,0.017307,0.017208,0.01711,0.017542,0.0175,0.017455,0.017479,0.017427,0.017684,0.01765,0.017679,0.017669,0.017654"Min:0;Max:1"])

aux growth_MEA_GlOrc = GRAPH(TIME,2011,1,[0.030753,0.029979,0.029245,0.028414,0.0292,0.029262,0.029295,0.029422,0.029631,0.030252,0.030463,0.030416,0.030554,0.030653,0.031399,0.031483,0.031439,0.031547,0.031444,0.031738,0.031571,0.031547,0.031419,0.031421,0.031322,0.031133,0.030933,0.030853,0.030625,0.03082,0.030494,0.030286,0.030068,0.029844,0.030249,0.029822,0.029407,0.029051,0.02889,0.029085,0.028752,0.028467,0.028099,0.027862,0.027226,0.026775,0.026416,0.02603,0.025691,0.025188,0.024739,0.024374,0.024021,0.023711,0.023997,0.023646,0.023335,0.023063,0.02274,0.022565,0.022337,0.022112,0.021892,0.0217,0.021536,0.021348,0.021162,0.021001,0.020819,0.021329,0.021079,0.020879,0.020661,0.020467,0.019957,0.019861,0.019744,0.019665,0.019563,0.019406,0.019429,0.019427,0.019417,0.019434,0.018882,0.018857,0.018842,0.018821,0.018811"Min:0;Max:1"])

aux growth_MEA_GSusDev = GRAPH(TIME,2011,1,[0.022894,0.022229,0.021746,0.020991,0.021416,0.021806,0.021751,0.022091,0.022269,0.023065,0.023171,0.023381,0.023445,0.023726,0.024318,0.024409,0.02448,0.024745,0.024769,0.024778,0.024869,0.02494,0.025085,0.025112,0.025034,0.02512,0.02527,0.025228,0.025417,0.025892,0.026008,0.026024,0.026095,0.026215,0.026586,0.026574,0.026545,0.0265,0.026566,0.026853,0.026625,0.026512,0.026277,0.026098,0.026236,0.025877,0.025529,0.02524,0.024957,0.024773,0.024404,0.024047,0.023745,0.023408,0.023625,0.023284,0.022994,0.02275,0.022435,0.022577,0.022371,0.022095,0.021932,0.021735,0.02144,0.021252,0.021066,0.020914,0.020731,0.021003,0.020778,0.020586,0.020398,0.02024,0.020628,0.020531,0.020405,0.02033,0.020251,0.020513,0.02051,0.020523,0.020504,0.0205,0.020711,0.020704,0.020689,0.020688,0.020658"Min:0;Max:1"])

aux growth_MEA_OfS = GRAPH(TIME,2011,1,[0.0149,0.0143,0.014,0.0136,0.0136,0.0137,0.0135,0.0135,0.0135,0.0131,0.013,0.0129,0.0128,0.0125,0.0125,0.0122,0.012,0.0118,0.0116,0.011,0.0108,0.0106,0.0104,0.0103,0.0098,0.0096,0.0094,0.0092,0.009,0.0092,0.0089,0.0088,0.0086,0.0085,0.0088,0.0086,0.0086,0.0083,0.0084,0.0089,0.009,0.0092,0.0092,0.0093,0.0096,0.0096,0.0097,0.0098,0.0099,0.0106,0.0108,0.0107,0.0109,0.0107,0.0114,0.0112,0.0114,0.0114,0.0114,0.0117,0.0118,0.0118,0.0119,0.012,0.0127,0.0128,0.0129,0.0129,0.0129,0.0135,0.0136,0.0135,0.0137,0.0136,0.0142,0.0142,0.0142,0.0141,0.0142,0.0143,0.0143,0.0144,0.0144,0.0144,0.015,0.0151,0.0151,0.0151,0.0152"Min:0;Max:1"])

aux growth_pop = growth_pop_proj_UN

aux growth_pop_GlOrc =
GRAPH(TIME,2011,1,[0.008627,0.008553,0.008481,0.008409,0.007208,0.007297,0.007244,0.007192,0.007141,0.006136,0.006098,0.006196,0.006024,0.006121,0.004894,0.00487,0.004977,0.004822,0.004799,0.004002,0.003986,0.00397,0.003827,0.003939,0.003038,0.003028,0.003019,0.00301,0.003001,0.002119,0.002239,0.00211,0.00223,0.002101,0.001727,0.001724,0.001721,0.00184,0.001715,0.001223,0.001221,0.00122,0.001218,0.001217,-0.000122,0,0,0,0,-0.00158,-0.001461,-0.001463,-0.001465,-0.001589,-0.002082,-0.002209,-0.002214,-0.002219,-0.002224,-0.002848,-0.002856,-0.002739,-0.002872,-0.00288,-0.003893,-0.004034,-0.003924,-0.004067,-0.003956,-0.003971,-0.003987,-0.004132,-0.00402,-0.004036,-0.004314,-0.004201,-0.004219,-0.004369,-0.004255,-0.006944,-0.006859,-0.007041,-0.007091,-0.007142,-0.009268,-0.009495,-0.009586,-0.009678,-0.009773"Min:0;Max:1"])

doc growth_pop_GlOrc = Proyecciones de MEA2005 en su escenario medio Global Orchestration

aux growth_pop_GSusDev =
GRAPH(TIME,2011,1,[0.010757,0.010643,0.010531,0.010421,0.009488,0.009263,0.009313,0.009093,0.009011,0.008012,0.007818,0.007886,0.007696,0.007765,0.006694,0.006524,0.006607,0.00644,0.006521,0.005746,0.005713,0.00556,0.005649,0.005617,0.004873,0.004967,0.004825,0.004919,0.004779,0.003944,0.003813,0.003913,0.003784,0.003769,0.002959,0.00295,0.002828,0.002933,0.002812,0.002467,0.002461,0.002344,0.00245,0.002333,0.001884,0.00177,0.001877,0.001763,0.00176,0.000879,0.000878,0.000877,0.000876,0.000875,0.000109,0.000109,0.000109,0.000219,0.000109,-0.000328,-0.000219,-0.000328,-0.000328,-0.000219,-0.001641,-0.001644,-0.001647,-0.001649,-0.001652,-0.002096,-0.002211,-0.002105,-0.00211,-0.002225,-0.002007,-0.002011,-0.002015,-0.00202,-0.002024,-0.001915,-0.001806,-0.001922,-0.001813,-0.001929,-0.002729,-0.002737,-0.00263,-0.002751,-0.002759"Min:0;Max:1"])

doc growth_pop_GSusDev = Proyecciones de MEA2005 en su escenario medio Global Orchestration

aux growth_pop_MEA_AdapMos =
GRAPH(TIME,2011,1,[0.012555,0.012399,0.012247,0.012099,0.010745,0.010631,0.010519,0.01028,0.010304,0.009306,0.009221,0.009136,0.009054,0.008972,0.00804,0.007976,0.007913,0.007851,0.007789,0.007378,0.007208,0.007271,0.007219,0.007167,0.006664,0.00662,0.006465,0.006534,0.006492,0.005576,0.005653,0.005514,0.005483,0.00556,0.004679,0.004763,0.00474,0.004718,0.004591,0.004363,0.004344,0.004222,0.004307,0.004288,0.00366,0.003647,0.003633,0.00352,0.003608,0.002596,0.00249,0.002484,0.002477,0.002471,0.001578,0.001674,0.001573,0.00157,0.001568,0.001076,0.001075,0.000976,0.001073,0.000974,-0.000292,-0.000389,-0.00039,-0.00039,-0.00039,-0.001073,-0.001074,-0.001075,-0.001174,-0.001077,-0.001176,-0.001178,-0.001179,-0.001181,-0.001182,-0.001381,-0.001284,-0.001384,-0.001386,-0.001289,-0.002482,-0.002488,-0.002495,-0.002501,-0.002507"Min:0;Max:1"])

doc growth_pop_MEA_AdapMos = Popoluation MEA Order from Strengh scenario

aux growth_pop_MEA_OfS =
GRAPH(TIME,2011,1,[0.012696,0.012397,0.012383,0.012096,0.011011,0.010891,0.010774,0.010659,0.010547,0.009673,0.00958,0.009489,0.0094,0.009313,0.008377,0.008307,0.008239,0.00829,0.008104,0.007573,0.007516,0.007575,0.007404,0.007463,0.006622,0.006578,0.006646,0.006492,0.00656,0.005431,0.005509,0.005479,0.005449,0.005313,0.004545,0.004525,0.004505,0.004484,0.004464,0.004134,0.004117,0.003998,0.004084,0.004068,0.003545,0.003532,0.003419,0.003508,0.003495,0.003384,0.003372,0.003361,0.00335,0.003339,0.003132,0.003122,0.003209,0.003102,0.003093,0.00212,0.002211,0.002111,0.002202,0.002101,0.001906,0.001903,0.001899,0.001896,0.001797,0.001228,0.001132,0.00113,0.001129,0.001128,0.000188,0.000094,0.000094,0.000188,0.000094,-0.000094,-0.000188,-0.000094,-0.000188,-0.000094,-0.000188,-0.000188,-0.000188,-0.000094,-0.000188"Min:0;Max:1"])

doc growth_pop_MEA_OfS = Popoluation MEA Order from Strengh scenario aux growth_pop_proj_UN = GRAPH(TIME,2011,1,[0.0112,0.011,0.0109,0.0107,0.0105,0.0102,0.01,0.0098,0.0096,0.0093,0.0091,0.0089,0.0087,0.0085,0.0082,0.008,0.0078,0.0076,0.0074,0.0073,0.0071,0.0069,0.0067,0.0065,0.0064,0.0062,0.006,0.0058,0.0057,0.0055,0.0053,0.0052,0.005,0.0048,0.0047,0.0045,0.0044,0.0042,0.004,0.0039,0.0037,0.0036,0.0035,0.0033,0.0032,0.0031,0.0029,0.0028,0.0027,0.0026,0.0025,0.0024,0.0023,0.0022,0.0021,0.002,0.002,0.0019,0.0018,0.0017,0.0017,0.0016,0.0015,0.0015,0.0014,0.0013,0.0013,0.0012,0.0012,0.0011,0.0011,0.001,0.001,0.0009,0.0009,0.0009,0.0008,0.0008,0.0008,0.0008,0.0007,0.0007,0.0007,0.0006,0.0006,0.0006,0.0006,0.0005,0.0005"Min:0;Max:1"])

doc growth_pop_proj_UN = Proyecciones de Naciones Unidas [UN2010] en su escenario medio (Medium fertility variant).

aux GtC_historic_emissions_RCPs = GRAPH(TIME,1990,5,[6.144,6.4395,6.735,7.971"Min:0;Max:40"])

doc GtC_historic_emissions_RCPs = RCP database: http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=welcome

aux GtCO2_historic_emissions_RCPs = (11/3)*GtC_historic_emissions_RCPs

aux GtCO2e_biomass = E_BioW_production_TWh*0*10^(-6)

doc GtCO2e_biomass = ? gCO2e/KWh [Arvesen 2011]. (1 g/KWh = 0.001 Gt/TWh)

aux GtCO2e_electric_renewables = GtCO2e_wind_1+GtCO2e_geot_1+GtCO2e_hydro_1+GtCO2e_oceanic_1+GtCO2e_solar_1

aux GtCO2e_geothermal = E_geot_production_TWh*35*10^(-6)

doc GtCO2e_geothermal = 15.1-55 gCO2e/KWh [Arvesen 2011]. (1 g/KWh = 0.001 Gt/TWh)

aux GtCO2e_hydro = E_hydro_production_TWh*20*10^(-6)

doc GtCO2e_hydro = 17-22 gCO2e/KWh [Arvesen 2011]. (1 g/KWh = 0.001 Gt/TWh)

aux GtCO2e_nuclear = E_Nuclear_TWh_production*40*10^(-6)

doc GtCO2e_nuclear = 9-70 gCO2e/KWh [Arvesen 2011]. (1 g/KWh = 0.001 Gt/TWh)

aux GtCO2e_oceanic = E_oceanic_production_TWh*17*10^(-6)

doc GtCO2e_oceanic = 14-21.7 gCO2e/KWh [Arvesen 2011]. (1 g/KWh = 0.001 Gt/TWh)

aux GtCO2e_solar = E_solar_production_TWh*25*10^(-6)

doc GtCO2e_solar = PV: 19-59 // CSP: 8.5-11.3 gCO2e/KWh [Arvesen 2011]. (1 g/KWh = 0.001 Gt/TWh)

aux GtCO2e_wind = E_wind_production_TWh*5*10^(-6)

doc GtCO2e_wind = 2.8-7.4 gCO2e/KWh [Arvesen 2011]. (1 g/KWh = 0.001 Gt/TWh)

aux GTL_Gb = GTL_EJ*(1/5.582)

aux GTL_Mtoe = GTL_EJ*(1000/41.868)

aux help_to_EV = production_EV*1000*1.4/(1e12)

doc help_to_EV = Pongo entre 500 y 1000 euros en subvenciones y ayudas directas, suponiendo que todo el mundo hiciera lo mismo que planean algunos paises de la UE en ayudas directas e infraestructuras, en T$

aux Hist_propor_gas_E = GRAPH(TIME,1990,1,[0.234799,0.2342967,0.2343599,0.2378617,0.2413746,0.2469295,0.2465493,0.2559208,0.2625459,0.2760204,0.2773652,0.2891031,0.2950195,0.2942323,0.303594,0.3040966,0.3057229,0.3114932,0.3186107,0.3249556,0.3316873"Min:0;Max:1"])

doc Hist_propor_gas_E = Data extracted from database World Bank: "Electricity production from gas sources (% of total) " / "Electricity production from oil, gas and coal sources (% of total)"

aux Hist_propor_oil_E = GRAPH(TIME,1990,1,[0.1645465,0.1620609,0.1568338,0.1485761,0.1434018,0.1381906,0.1321485,0.1296658,0.1311742,0.1231733,0.1138575,0.1084995,0.1027688,0.09614213,0.09292716,0.08753774,0.0784417,0.07473207,0.07121953,0.06888107,0.06358159"Min:0;Max:1"])

doc Hist_propor_oil_E = Data extracted from database World Bank: "Electricity production from oil sources (% of total) " / "Electricity production from oil, gas and coal sources (% of total)"

aux Historic_Biofuels_IEA = GRAPH(TIME,2000,1,[15.30891,16.6861,19.63532,24.30454,26.99819,31.93866,40.90777,53.6943,71.89628,79.5901,90.78115"Min:0;Max:1"])

doc Historic_Biofuels_IEA = Datos reales sacados de [IEAdb] "Biofuel production", y convertidos a Mtoe/año en /calibración - datos hisitóricos/Fuentes energéticas_Calibración datos hist.xls

aux Historic_Coal_IEA = GRAPH(TIME,1990,1,[2264.966,2155.455,2141.69,2082.985,2125.758,2179.364,2215.102,2337.323,2349.306,2326.685,2361.079,2471.558,2543.509,2697.305,2851.861,3097.434,3271.258,3408.71,3533.601,3643.009,3805.689,4048.198"Min:0;Max:1"])

doc Historic_Coal_IEA = Datos reales sacados de [IEAdb] "Coal production" en Q Btu, y convertidos a Mtoe/año en /calibración - datos hisitóricos/Fuentes energéticas_Calibración datos hist.xls

aux Historic_energy_intensity = Historic_Primary_energy_IEA/GDP_1

aux Historic_Gas_IEA = GRAPH(TIME,1990,1,[1918.671,1950.541,1953,1989.333,2003.976,2030.921,2092.656,2091.352,2128.955,2180.32,2264.819,2310.176,2354.833,2429.487,2486.824,2558.47,2652.032,2705.491,2799.684,2734.628,2911.088,3054.411"Min:0;Max:1"])

doc Historic_Gas_IEA = Datos reales sacados de [IEAdb] "Dry Natural gas", categoría que incluye el gas que se extrae útil descontando pérdidas y reinyecciones, en bcf. Conversión a Mtoe con la equivalencia del US EIA (1 bcf=195.019 boe) y 1 Mtoe = 1 boe. Mtoe/año en /calibración - datos hisitóricos/Fuentes energéticas_Calibración datos hist.xls

aux Historic_Liquids_IEA = GRAPH(TIME,1990,1,[3233.204,3228.503,3238.891,3265.598,3340.317,3421.492,3503.323,3612.028,3683.129,3642.139,3782.419,3779.298,3750.773,3869.468,4041.053,4113.322,4112.422,4104.919,4159.852,4116.263,4236.816,4250.139,4335.72"Min:0;Max:1"])

doc Historic_Liquids_IEA = Datos reales sacados de [IEAdb] "Total Oil Supply", categoría que incluye todos los líquidos y convertidos a Mtoe/año en /calibración - datos hisitóricos/Fuentes energéticas_Calibración datos hist.xls

aux Historic_Primary_energy_IEA = GRAPH(TIME,1990,1,[8784.935,8719.354,8724.766,8753.513,8903.011,9114.885,9335.752,9563.993,9698.562,9709

.883,10006.88,10154.6,10240.15,10602.15,11071.6,11500.67,11796.05,11975.74,12305.79,12280.37,12823.51"Min:0;Max:1"])

doc Historic_Primary_energy_IEA = Datos reales sacados de [IEAdb] "Total Primary Energy Production", convertidos a Mtoe/año en /calibración - datos hisitóricos/Fuentes energéticas_Calibración datos hist.xls

aux historic_TWh_nuclear = GRAPH(TIME,1990,1,[1908.807,1996.14,2015.603,2081.627,2125.16,2210.045,2291.532,2271.307,2316.009,2393.132,2449.889,2516.674,2545.302,2517.757,2617.323,2639.244,2659.825,2597.7,2602.65,2568.41,2620.22,2507.24"Min:0;Max:3000"])

doc historic_TWh_nuclear = Datos de [tonto.eia] hasta 2011 incluido

aux Historic_unconv_oil = GRAPH(TIME,1990,1,[1.955933,2.04395,2.135928,2.232044,2.332486,2.437448,2.547133,2.661754,2.781533,2.906702,3.037504,3.174192,3.31703,3.466296,3.62228,3.785282,3.95562,4.133623,4.319636,4.51402,4.717151"Min:0;Max:1"])

doc Historic_unconv_oil = Según [de Castro 2009], el crecimiento medio en los últimos años fue del +4.5% anual. Ajusto según los datos de [Grushevenko 2012], la producción en 2010 fue de 2.3 Mb/d.

aux Historical_a_Transp_Intensity = GRAPH(TIME,1990,1,[0.9990634,1.004318,0.9948779,0.9978247,0.9942701,1.001174,0.9861589,0.9909408,1.004554,0.9910916,0.9629158,1.003049,1.006062,1.007066,0.9909275,0.9919123,1,1"Min:0;Max:1"])

doc Historical_a_Transp_Intensity = Calculado en: Investigación - Bibliografia\Intensidad E por sectores/GDP_Pop_intensities input.xlsx

aux hydro_primary_E_demand_Mtoe = E_hydro_production_EJ*(1000/41.868)

doc hydro_primary_E_demand_Mtoe = Conversión de la producción eléctrica a Mtoe

aux I_after_efficiency_EJ = I_coal+I_gas+I_Liquids+I_renew

doc I_after_efficiency_EJ = Este es la energía realmente demandada por el sector industrial tras la transición a eficiencia-renovables.

aux I_after_renew = Industrial_EJ*(1-percent_saving_I)

aux I_coal = I_after_renew*propor_i_coal

doc I_coal = Energía primaria del sector Industrial cubierto por carbón.

aux I_gas = I_after_renew*propor_i_gas

doc I_gas = Energía primaria del sector Industrial cubierto por gas natural.

aux I_Liquids = I_after_renew*propor_i_liquids

doc I_Liquids = Energía primaria del sector Industrial cubierto por combustibles líquidos.

aux I_renew = I_after_renew*propor_i_renew+I_renew_efficiency

aux I_renew_efficiency = percent_saving_I*Industrial_EJ/2 doc I_renew_efficiency = Energía primaria del sector Industrial cubierto por renovables. ¿multiplicar por un factor para representar el ahorro-eficiencia de energía primaria en la sustitución por EERR?)

aux Icir_min = Icir_2007*0.25

doc Icir_min = 4 En función de cada escenario. Si esta variable es nula, entonces es como si aplicamos la fórmula de la intensidad energética convencional.

aux Ielec_min = Ielec0_2010*0.25

doc Ielec_min = En función de cada escenario. Si esta variable es nula, entonces es como si aplicamos la fórmula de la intensidad energética convencional.

aux IF_abund_Coal = IF(abund_coal>-0.05,0,TIME)

aux IF_abund_Electricity = IF(Abund_electricity>-0.05,0,TIME)

aux IF_abund_Gas = IF(abund_gas>-0.05,0,TIME)

aux IF_abund_Hydro = IF(abund_hydro>0.05,0,TIME)

aux IF_abund_IB = IF(abund_CIR>-0.05,0,TIME)

aux IF_abund_Liquids = IF(Abund_liquids>-0.05,0,TIME)

aux IF_abund_Solar = IF(abund_solar>0.05,0,TIME)

aux IF_abund_TPE = IF(abund_TPE>-0.05,0,TIME)

aux IF_abund_Transport = IF(abund_Transport>-0.05,0,TIME)

aux IF_abund_Uranium = IF(abund_uranium>-0.05,0,TIME)

aux IF_abund_Wind = IF(abund_wind>0.05,0,TIME)

aux incr_deficit_energy = IF(TIME>2008,(dem_Prim_E_Mtoe_after_policies*41.868/1000-extraction_total_EJ_2)/(dem_Prim_E_Mtoe_after_policies*41.868/1000),0)

aux incr_deficit_energy_delayed_1yr = DELAYINF(incr_deficit_energy,1,1,0)

aux increase_E_EV_TWh = liquid_saved_EV_HEV_EJ*K_liquid_E_EV_TWh_EJ

doc increase_E_EV_TWh = TWh que se consumen mas por pasarse a electricidad. .factor de intercambio entre oil y E, basado en las necesidades comparadas de transporte con coche eléctrico (que no sé si es extrapolable a otros tipos de transporte). Sacado de datos de PPP suponiendo 103 litros de combustibles. liquidos por cada barril de petroleo como PPP. 155 TWh/Gbarril

aux Increase_E_total_EJ = Increase_E_total_TWh*(3.6/1000)

doc Increase_E_total_EJ = Conversión a TWh de los EJ eléctricos calculados.

aux Increase_E_total_TWh = increase_E_EV_TWh+increase_E_train_TWh

doc Increase_E_total_TWh = Incremento de demanda de energía eléctrica por sustitución de combustibles líquidos -coches y camiones- por coche eléctrico y tren, respectivamente.

aux increase_E_train_TWh = Liquid_saved_for_E_train*K_liquid_E_train_TWh_EJ doc increase_E_train_TWh = TWh que se consumen de más por la política de fomento del tren.

aux increase_emissions_GTL_CTL_GtCO2 = (CTL_Mtoe*1.75*3.96+GTL_Mtoe*2.35*1.85)/1000

doc increase_emissions_GTL_CTL_GtCO2 = según [Farrel&Brandt 2007] CTL: 45.25 gC/MJ (=6.94 tCO2/toe) y 28.28 gC/MJ (=4.34 tCO2/toe). Aplico porcentajes respecto del coal y gas convencional para añadir.

aux Industrial_EJ = CIR_EJ*propor_industrial

doc Industrial_EJ = Energía primaria consumida por el sector Industrial (sin contar la electricidad).

aux invest_biofuels_Tdolar = BioLiquids_available_EJ*0

doc invest_biofuels_Tdolar = (biofuels1_oil_eq_Gbb+biofuels2_oil_eq_Gbb)*0.112*0 [Tdolar / Gboe] marga: 0.644 [?]. pongo el valor sacado de REN21 y BP calculado según inv/incr(producción año siguiente)

aux invest_bioW_Tdolar = IF(TIME<2060,new_BioW_TWe*Invest_cost_BioW,new_BioW_TWe*3.2228)

doc invest_bioW_Tdolar = Según 5.12 (incremento de generación eléctrica de origen biomasa+residuos 2007-08) y 11.3 (inversión en el año 2007)

aux Invest_cost_BioW = GRAPH(TIME,1990,10,[3.904458,3.904458,3.904458,3.373795,3.293434,3.254639,3.222771"Min:0;Max:40"])

doc Invest_cost_BioW = Datos extraídos de Energy [R]evolution 2010 [Teske et al., 2011]. Detalles en /RENOVABLES/costes capital_learning curve_gen EERR.xls

aux Invest_cost_geot = GRAPH(TIME,1990,10,[15.90322,15.90322,15.90322,11.73511,9.263889,7.720333,6.639333"Min:0;Max:40"])

doc Invest_cost_geot = Datos extraídos de Energy [R]evolution 2010 [Teske et al., 2011]. Detalles en /RENOVABLES/costes capital_learning curve_gen EERR.xls

aux Invest_cost_hydro = GRAPH(TIME,1990,10,[4.785769,4.785769,4.785769,6.062143,6.335268,6.682545,6.887455"Min:0;Max:40"])

doc Invest_cost_hydro = Datos extraídos de Energy [R]evolution 2010 [Teske et al., 2011]. Detalles en /RENOVABLES/costes capital_learning curve_gen EERR.xls

aux Invest_cost_oceanic = GRAPH(TIME,1990,10,[36.88178,23.05111,9.220444,3.585444,2.757444,2.302556,2.050833"Min:0;Max:40"])

doc Invest_cost_oceanic = Datos extraídos de Energy [R]evolution 2010 [Teske et al., 2011]. Detalles en /RENOVABLES/costes capital_learning curve_gen EERR.xls

aux Invest_cost_solar = GRAPH(TIME,1990,10,[46.875,31.25,26.92438,12.765,7.381563,7.381563,7.381563"Min:0;Max:50"])

doc Invest_cost_solar = Datos extraídos de Energy [R]evolution 2010 [Teske et al., 2011]. "Congelo" el coste de 2030 en adelante por considerarlo excesivamente optimista (salía menor que el coste de la eólica!) Detalles en /RENOVABLES/costes capital_learning curve_gen EERR.xls

aux Invest_cost_wind = GRAPH(TIME,1990,10,[33.07619,20.67262,8.269048,6.949286,6.604286,6.122381,6.021071"Min:0;Max:40"]) doc Invest_cost_wind = Datos extraídos de Energy [R]evolution 2010 [Teske et al., 2011]. Detalles en /RENOVABLES/costes capital_learning curve_gen EERR.xls

aux invest_E_renew = invest_wind_Tdolar+invest_biomass_Tdolar_2+invest_geot_Tdolar_2+invest_hydro_Tdolar_2+invest_oceanic_Tdolar_2+invest_solar_Tdolar_2

aux invest_geot_Tdolar = IF(TIME<2060,new_geot_TWe*Invest_cost_geot,new_geot_TWe*6.639333)

doc invest_geot_Tdolar = [T$/TWe] Según 5.12 (incremento de generación eléctrica de origen geotérmico 2007-08) y 11.3 (inversión en el año 2007)

aux invest_hydro_Tdolar = IF(TIME<2060,new_hydro_TWe*Invest_cost_hydro,new_hydro_TWe*6.887455)

doc invest_hydro_Tdolar = Según 5.12 (incremento de generación eléctrica de origen hidroeléctrico 2007-08) y 11.3 (inversión en el año 2007)

aux invest_nuclear_Tdolar = new_nuclear_TWe*4.15

aux invest_oceanic_Tdolar = IF(TIME<2060,new_oceanic_TWe*Invest_cost_oceanic,new_oceanic_TWe*2.050833)

doc invest_oceanic_Tdolar = No tengo datos (aún se encuentra en fase de investigación)

aux invest_renew_vs_GDP_100 = invest_total_renew_Tdolar*100/GDP_3

aux invest_solar_Tdolar = IF(TIME<2060,new_solar_TWe*Invest_cost_solar, new_solar_TWe*5.47)

doc invest_solar_Tdolar = A partir de 2060, como [Teske et al 2010] no estima más allá de 2050, lo suponemos constante.

aux invest_total_renew_Tdolar = invest_E_renew+extra_invest_variable_renew+invest_biofuels_Tdolar_2

doc invest_total_renew_Tdolar = [T$] Total de las inversiones en renovables: coste de las tecnologías + mejora de la infraestructura. Según datos de 11.3 la inversión en 2009 fue de 0.15 T$ (sin contar inversión en mejora de la infraestructura).

aux invest_wind_Tdolar = IF(TIME<2060,new_wind_TWe*Invest_cost_wind,new_wind_TWe*6.021)

doc invest_wind_Tdolar = A partir de 2060, como [Teske et al 2010] no estima más allá de 2050, lo suponemos constante.

aux Itransp_min = Itransp_2015*0.25

doc Itransp_min = En función de cada escenario. Si esta variable es nula, entonces es como si aplicamos la fórmula de la intensidad energética convencional.

aux Land_Biofuel_compet = BioE_2a_gen_EJ_compet*21.14

aux Land_biofuel_marg = BioE_2a_gen_EJ_marg*14.15/Conv_EJ_EJ

aux Liquid_saved_by_E_total_EJ = liquid_saved_EV_HEV_EJ+Liquid_saved_for_E_train

doc Liquid_saved_by_E_total_EJ = Total ahorro en combustibles líquidos tras aplicación de las políticas de sustitución por el coche eléctrico y el tren.

aux liquid_saved_EV_HEV_EJ = Liquid_transport_initial_EJ*(change_to_EV_percent+(1/3)*change_to_HEV_percent)

doc liquid_saved_EV_HEV_EJ = Ahorramos una cantidad en líquidos con el coche eléctrico y luego en base a ello calculamos los coches eléctricos que hemos metido para sustituirlo.

aux Liquid_saved_for_E_train = Liquid_transport_initial_EJ*change_to_E_percent_train

doc Liquid_saved_for_E_train = Ahorramos una cantidad de petróleo con el tren. Le restamos el 1% (media 1990-2009 [WEO 2010]) de transporte eléctrico correspondiente al ferrocarril.

aux liquid_saved_NGV = change_to_NGV_percent*Liquid_transport_initial_EJ

doc liquid_saved_NGV = 1<=>1. "CNG vehicles are currently slightly less efficient than equivalent gasoline vehicles while diesel vehicles enjoy a net advantage. In the future, however, improvements in spark ignition engines will bring all technologies much closer together" (IET JRC, 2014).

aux Liquid_transport_initial_EJ = Dem_Transport_initial_EJ*(1-propor_gas_losses-propor_E)

doc Liquid_transport_initial_EJ = Parte de la demanda del sector transporte cubierta por Líquidos,

aux Liquids_supply_EJ = extraction_crude_oil_EJ+CTL_and_GTL_EJ_1+Refinery_gains_EJ+Liquid_saved_by_bio_EJ_2

aux Liquids_supply_Mtoe = Liquids_supply_EJ*(1000/41.868)

aux lithium_on_cars = 12*number_of_EV_on_the_road

doc lithium_on_cars = Kg de litio en vehiculos. Lo dejamos en 12 Kg litio por vehiculo, una media entre los valores de diversas fuentes

aux Mauna_Loa_ppm = GRAPH(TIME,1959,1,[315.97,316.91,317.64,318.45,318.99,319.62,320.04,321.38,322.16,323.04,324.62,325.68,326.32,327.45,329.68,330.18,331.08,332.05,333.78,335.41,336.78,338.68,340.1,341.44,343.03,344.58,346.04,347.39,349.16,351.56,353.07,354.35,355.57,356.38,357.07,358.82,360.8,362.59,363.71,366.65,368.33,369.52,371.13,373.22,375.77,377.49,379.8,381.9,383.76,385.59,387.37,389.85,391.63,393.82"Min:0;Max:1"])

aux Max_BioE_2a_gen_compet = conv_MHa_EJ*extra_MHa_compet

doc Max_BioE_2a_gen_compet = Potencial según [Field2008] en tierras no cultivadas actualmente: 386 Mha, pero aplicando el coeficiente de [Castro&Carpintero] de 0.15 W/m2. A esto le añadimos un potencial "extra" de biofuels cultivados en zonas tropicales de alta productividad.

aux Max_BioE_2a_gen_marginal = 27*Conv_EJ_EJ

doc Max_BioE_2a_gen_marginal = Potencial según [Field2008] en tierras no cultivadas actualmente: 386 Mha, pero aplicando el coeficiente de [Castro&Carpintero] de 0.15 W/m2. A esto le añadimos un potencial "extra" de biofuels cultivados en zonas tropicales de alta productividad.

aux Max_BioE_3a_gen = (Max_BioE_2a_gen_compet+Max_BioE_2a_gen_marginal)*0.15

doc Max_BioE_3a_gen = Por mejora de la eficiencia se aumenta el potencial. Aumento del 15% estimado por el [WBGU2008]

aux max_BioW_TWe = 0.25+delivered_BioE_Electricity_TWe doc max_BioW_TWe = Para la biomasa consideramos que no va a aumentar mucho más porque priorizamos los BIOFUELS. Tengo que poner aqui la potencia máxima que se puede extraer de bioelectricidad y residuos (?) anualmente. En los últimos 20 años ha venido creciendo a una tasa del 6% anual. Pongo 4 veces más (?) de momento.

aux max_extraction_coal_Mohr2012_EJ = GRAPH(reserves_coal,0,2000,[0,50.9743,81.21,91.3165,96.3823,109.46,123.422,148.171,204.223,216.291,216.291,216.291,216.291,216.291,216.291"Min:0;Max:180;Zoom"])

doc max_extraction_coal_Mohr2012_EJ = Curva [Mohr2012] High Case. update de [Mohr2009]

aux max_extraction_coal_Mtoe = max_extraction_coal_Mohr2012_EJ*(1000/41.868)

aux max_extraction_gas_Mtoe = max_extraction_gasLaherrere2010_EJ*(1000/41.868)

aux max_extraction_gasLaherrere2010_EJ = GRAPH(reserves_gas,0,500,[0,23.86209,44.63101,62.30666,77.77291,93.88909,107.8214,119.7524,129.0326,137.8702,144.1604,148.9172,151.7803,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945,152.8945"Min:0;Max:160;Zoom"])

doc max_extraction_gasLaherrere2010_EJ = Curva Laherrere2010 de extracción de gas hasta 2100. Unidades: EJ. Para los puntos a partir del 2100 se ha realizado una exponencial negativa hasta anular las reservas en 2120.

aux max_extraction_H_Maggio12_oil_EJ = GRAPH(reserves_oil,0,500,[0,15.6384,43.73163,66.24827,87.34715,103.4157,119.4083,131.57,140.0565,150.2572,156.9316,162.6833,167.4624,171.2391,173.998,175.733,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516,176.4516"Min:0;Max:180;Zoom"])

doc max_extraction_H_Maggio12_oil_EJ = [Maggio2012]. Oil conventional+NGLs. Scenario con URR=2600 Gb.

aux max_extraction_oil_Mtoe = max_extraction_H_Maggio12_oil_EJ*(1000/41.868)

aux max_extraction_uranium_EJ = GRAPH(reserves_uranium_EJ,0,300,[0,10.03061,23.76488,33.48686,39.96821,44,44,44,44,44,44,44,44,44"Min:0;Max:44;Zoom"])

doc max_extraction_uranium_EJ = [Zittel2012]

aux MESSAGE_IPCC_A1G_GtC_cumulated = GRAPH(TIME,1990,10,[0,75.3,162.9,265.1,390.3,549,744.1,981.7,1257.3,1555.3,1863.7,2170.9"Min:0;Max:1"])

aux MESSAGE_IPCC_A2_GtC_cumulated = GRAPH(TIME,1990,10,[0,75.3,162.5,267,391,530.7,683.4,848.2,1027.2,1227.6,1459.2,1725.2"Min:0;Max:1"])

aux MESSAGE_IPCC_B1_GtC_cumulated = GRAPH(TIME,1990,10,[0,75.3,160.4,251.5,343.6,436.2,525.3,606.8,679.2,741.9,794,837.4"Min:0;Max:1"])

aux net_Biofuels_historic_2011_Gboe = GRAPH(TIME,1990,1,[0.05199342,0.05790025,0.05612665,0.05704326,0.06433706,0.06573919,0.06797722,0.07639393,0.07183906,0.07062136,0.06707071,0.07344909,0.08670619,0.1076111,0.1202112,0.1443951,0.1879846,0.2536929,0.3376095,0.3796708,0.4284504,0.4314643"Min:0;Max:1;Zoom"])

doc net_Biofuels_historic_2011_Gboe = Datos de [BP2012] En Gb tal cual vienen en el excel.

aux New_BioW_without_repl = IF(TIME<2010,past_BioW*BioW_TWe,Adapt_growth_BioW*BioW_TWe)

doc New_BioW_without_repl = [% anual] Ritmo de crecimiento de la eólica en 5 años (2005-2009) según 11.3.

aux New_geot_without_repl = IF(TIME<2010,past_geot*geot_TWe,Adapt_growth_geot*geot_TWe)

doc New_geot_without_repl = Según [tonto.eia], en el periodo 1990-2010 el crecimiento anual fue del 3.3%.

aux New_hydro_without_repl = IF(TIME<2010,past_hydro*hydro_TWe,Adapt_growth_hydro*hydro_TWe)

doc New_hydro_without_repl = [% anual] Ritmo de crecimiento de la eólica en 5 años (2005-2009) según 11.3.

aux New_oceanic_without_repl =
IF(TIME<2010,past_oceanic*oceanic_TWe,Adapt_growth_oceanic*oceanic_TWe)

aux New_solar_without_repl = IF(TIME<2010,past_solar*solar_TWe,Adapt_growth_solar*solar_TWe)

doc New_solar_without_repl = [% anual] Ritmo de crecimiento de la eólica en 5 años (2005-2009) según 11.3.
IF(TIME<2010,past_eolic_1*eolic_TWe_1,Adapt_growth_eolic_1*eolic_TWe_1)-repl_eolic_1

aux New_wind_without_repl = IF(TIME<2010,past_wind*wind_TWe,Adapt_growth_wind*wind_TWe)

aux nonRenew_E_TWh_production =
E_coal_production_TWh_1+E_gas_production_TWh_1+E_oil_production_TWh_1+Nuclear_production_TWh_1

aux nuclear_priority = IF((Demand_E_nr_TWh>dem_Nuclear_TWh),dem_Nuclear_TWh,Demand_E_nr_TWh)

doc nuclear_priority = Dentro de la generación no renovable, damos prioridad a la de origen nuclear por sus características.

aux number_EV_delayed = DELAYINF(number_of_EV_on_the_road, 5,1,0)

aux number_of_EV_on_the_road = Oil_saved_for_E2*liters_per_barrel*1e9/consum_average_CV

doc number_of_EV_on_the_road = Numero de coches electricos, teniendo como estandar un turismo medio, que hacen falta para sustituir el porcentaje de petroleo que se ahorra. Sera igual a: numero coches = barriles de petroleo ahorrados x litros de gasolina/barril x barril/Gb x (1/litros gasolina que gasta un coche) -- esto es: oil_saved_for_E*1e9*liters_per_barrel/consum_average_CV tambien esto podriamos calcularlo como simplemente dividiendo los vehiculos (806e6 solo ligeros y coches fallo) entre los barriles gastados en transporte 30*0.6. oil_saved_for_E*4.5e7.

aux oceanic_production_Mtoe = E_oceanic_production_EJ*(1000/41.868)

doc oceanic_production_Mtoe = Conversión de la producción eléctrica a Mtoe

aux Oil_Castro_I =
GRAPH(TIME,1985,1,[2586.21,2657.238,2727.034,2795.637,2863.081,2929.387,2994.561,3058.576,3121.377,3182.869,3242.918,3301.346,3357.93,3412.405,3464.47,3513.786,3559.993,3602.718,3641.579,3676.207,3706.255,3731.413,3751.42,3766.075,3775.242,3778.863,3776.956,3769.611,3756.989,3739.309,3716.84,3688.035,3646.763,3592.805,3525.96,3446.962,3357.361,3259.305,3155.317,3048.036,2940.002,2833.899,2731.449,2633.989,2542.411,2457.184,2378.413,2305.916,2239.297,2178.03,2121.511,2067.406,2015.014,1963.69,1913.006,1862.722,1812.749,1763.118,1713.947,1665.408,1617.7,1569.242,1521.334,1474.425,1428.88,1378.914,1326.444,1276.275,1229.494,1186.637,1147.86,1113.073,1082.056,1054.527,1030.197,1008.794,990.0865,973.882,960.0305,948.4187,938.964,931.6077,926.3064,923.0253,921.7311,922.3853,924.9388,929.328,935.4695,943.2591,952.5689,963.2484,975.1227,987.9961,1001.654,1015.864,1030.382,1044.956,1059.326,1073.235,1086.426,1098.651,1109.674,1119.273,1127

.242,1133.401,1137.591,1139.681,1139.565,1137.172,1132.456,1125.405,1116.035,1104.392,1090.547,1074.598" Min:0;Max:1"])

aux Oil_Castro_II_Mtoe = GRAPH(TIME,1985,1,[2853.605,2932.693,3010.547,3087.215,3162.74,3237.156,3310.472,3382.671,3453.701,3523.467,3591.829,3658.603,3723.549,3786.388,3846.792,3904.397,3958.811,4009.623,4056.415,4098.78,4136.269,4169.568,4198.244,4222.148,4241.187,4255.331,4264.623,4269.172,4269.148,4264.781,4256.344,4242.113,4215.119,4174.811,4120.764,4053.659,3975.156,3887.669,3794.084,3697.453,3600.705,3506.777,3417.656,3334.639,3258.436,3189.167,3126.444,3069.497,3017.289,2968.647,2922.373,2873.737,2821.484,2764.724,2703.172,2637.043,2566.929,2493.688,2418.331,2341.936,2265.579,2190.285,2116.993,2046.543,1979.652,1909.205,1839.499,1776.009,1719.364,1669.547,1626.187,1588.743,1556.592,1529.084,1505.569,1485.408,1467.992,1452.74,1439.116,1426.628,1414.832,1403.339,1391.811,1379.965,1367.569,1354.44,1340.44,1325.472,1309.436,1293.544,1278.69,1264.852,1251.89,1239.628,1227.886,1216.495,1205.302,1194.168,1182.97,1171.597,1159.952,1147.952,1135.523,1122.604,1109.144,1095.102,1080.449,1065.164,1049.239,1032.671,1015.47,997.6508,979.2383,960.2639,940.7653,920.7861"Min:0;Max:1"])

aux Oil_Castro_III = GRAPH(TIME,1985,1,[2586.21,2657.238,2727.034,2795.637,2863.081,2929.387,2994.561,3058.576,3121.377,3182.869,3242.918,3301.346,3357.93,3412.405,3464.47,3513.786,3559.993,3602.718,3641.579,3676.207,3706.255,3731.413,3751.42,3766.075,3775.242,3778.863,3776.957,3769.559,3756.017,3735.729,3708.446,3672.294,3621.032,3554.529,3472.852,3377.149,3269.456,3152.433,3029.071,2902.393,2775.218,2649.975,2528.602,2412.501,2302.569,2199.244,2102.593,2012.404,1928.262,1849.636,1775.935,1705.895,1639.003,1574.789,1512.889,1453.038,1395.041,1338.765,1284.121,1231.049,1179.512,1129.486,1080.95,1033.889,988.2829,939.9159,888.9828,838.9213,790.4251,743.8892,699.4981,657.2968,617.2417,579.2403,543.1769,508.9297,476.3806,445.4227,415.9614,387.9153,361.2165,335.808,311.6429,288.6826,266.8945,246.2505,226.7259,208.2974,190.9427,174.6384,159.3601,145.0818,131.775,119.4089,107.9503,97.36357,87.61117,78.65368,70.45028,62.95921,56.13819,49.94475,44.33675,39.27273,34.71215,30.61577,26.94585,23.66634,20.74301,18.14354,15.83763,13.79698,11.99527,10.40818,9.013323,7.790148"Min:0;Max:1"])

aux oil_pc = ext_oil2*1e9/(Population_1*4.50)

doc oil_pc = comparado con el valor de 1985 (=1)

aux Oil_saved_by_bio_EJ = BioLiquids_available_EJ

doc Oil_saved_by_bio_EJ = en EJ, 5,71 EJ por Gbarril

aux Other_liquids_EJ = extraction_unconv_oil_EJ+Refinery_gains_EJ+CTL_and_GTL_EJ_1

aux Other_liquids_Transp_EJ = Other_liquids_EJ*propor_Transp_liquids

aux P_CTL = IF(abund_coal<0,0,IF(Abund_liquids>0,0.04,IF(Years_from_peakconvoil<10,P1_CTL,0.1)))

aux P_GTL = IF(abund_gas<0,0,IF(Abund_liquids>0,0.04,IF(Years_from_peakconvoil<10,P1_GTL,0.1)))

aux P_NGV = IF(abund_gas>-0.05,0.18,0)

doc P_NGV = 0.25/38 0.37/39 2050 segun escenario blue EV success del IEA 4.18, 37% de hibridos del stock de vehiculos en 2050, 39 años= politica optimista y realista y sostenible todas igual [Mediavilla2012]

aux P_nuclear_scen4 = IF(TIME<2012,0.025,0.10)*P_nuclear_scen_4 doc P_nuclear_scen4 = Antes de 2025 ponemos un 2.5% para que compense la depreciación, y a partir del 2025 estimulamos a tope. Si el escenario 4 no es el activado, entonces la variable P_nuclear_scen4 anula a 0 este parámetro. IF(TIME<2025,0.025,0.10)*P_nuclear_scen_4

aux P1 = IF(Abund_electricity>-0.05,IF(TIME<2021,0.011/8,0.022/8)/2,0)

doc P1 = 0.57/39 de IEA blue EV successs escenario para 2050, 57% en 39 años = politica optimistas, realista la mitad [Mediavilla2012] 0.0135 0.003 0.0065 0.013 A partir de 2012 policy lineal, cada año cambiamos un P1 el factor change_to_E que esta entre 0 y 1. Esto no puede ser mayor que 1/15 =0.06 que es el porcentaje de vehiculos que se sustituye cada año por su vida util (suponiendo que la vida util en el mundo sean 15 años). Tomando el valor 0.06 estaríamos suponiendo que todos los coches nuevos comprados a partir de esa fecha son eléctricos. [marga-estambul] El objetivo de los fabricantes en 2020 era el 10%, con esto (0.005 lineal) consigo el 10% de los de 2020 sustituibles, pero es muy optimista.

aux P1_adapt_unconv_oil = IF(TIME<2050,P1_unconv_oil,IF(TIME<2100,P1_unconv_oil+(0.035-P1_unconv_oil)*(TIME-2050)/50,0.035))

doc P1_adapt_unconv_oil = IF(TIME<2050,0.045,IF(TIME<2065,0.04, IF(TIME<2080,0.035,0.03))) como en [Castro et al., 2009], extrapolación tendencias históricas. High: +6.6% como [Grusevenko2012]

aux P1_BioW = IF(TIME<2035,0.07,P_residues)

doc P1_BioW = 0.07 Crecimiento medio del periodo 1990-2010 según [tonto.eia]: +6.4%. Para compensar la depreciación manteniendo la tendencia pasada: +8.7%

aux P1_geot = past_geot*1

doc P1_geot = 3.2 % según [tonto.eia] para el periodo 1990-2010.

aux P1_HEV = IF(Abund_electricity>-0.05,IF(TIME<2021,0.011/8,0.022/8)/2,0)

doc P1_HEV = 0.25/38 0.37/39 2050 segun escenario blue EV success del IEA 4.18, 37% de hibridos del stock de vehiculos en 2050, 39 años= politica optimista y realista y sostenible todas igual [Mediavilla2012]

aux P1_hydro = past_hydro*1

doc P1_hydro = el crecimiento anual medio 1990-2010 fue +2.33% anual [EIAdb]. Pero, como nos encontramos relativamente cerca del máximo, tenemos que poner un valor de "past_hydro" mayor hasta que coincide la producción histórica para el año 2010: +5%.

aux P1_I = IF(TIME<2014,0,0.001)

doc P1_I = IF(TIME<2014,0,0.003) 0.015 -- cada año 1.5 de ahorro, en 10 años un 20% de ahorro adicional (a parte del 9% ya conseguido con renovables en 2007), como los objetivos de la UE (20-20-20) según 12.1. 0.015 0.0044 0.005

aux P1_oceanic = IF(TIME>2020,0.20,0)

doc P1_oceanic = Pongo un crecimiento generoso desde 2020 (década en que se estima comenzará a ser comercial) puesto que cuando irrumpen en el mercado las nuevas tecnologías renovables, debido a que no existe nada instalada de antes, se alcanzan % muy altos.

aux P1_RC = IF(TIME<2014,0,0.001)

doc P1_RC = IF(TIME<2014,0,0.003) 0.015 -- cada año 1.5% de ahorro, en 10 años un 20% de ahorro adicinoal, como los objetivos de la UE (20-20-20) según 12.1. 0.015 0.0044 0.005

aux percent_oil_non_available = (-abundance_oil2)

doc percent_oil_non_available = Porcentaja de petroleo no disponible Gb dividido entre la demanda

aux percentage_dif_energy_historic_vs_estimated = (Historic_Primary_energy_IEA-extraction_total_Mtoe)*100/Historic_Primary_energy_IEA

aux percentage_renew_vs_total = Total_Renew_Prim_E_Mtoe*100/extraction_total_Mtoe

aux percentaje_dem_extrac_modelo = (dem_Prim_E_Mtoe_after_politics_1-extraction_total_Mtoe)/dem_Prim_E_Mtoe_after_politics_1

aux Prim_E_Castro_I = GRAPH(TIME,1985,1,[7173.132,7368.388,7560.948,7750.953,7938.545,8123.845,8306.943,8487.869,8666.596,8843.009,9016.909,9188.003,9355.897,9520.108,9680.064,9835.119,9984.568,10127.67,10263.69,10391.88,10511.56,10622.13,10723.08,10814.07,10894.85,10965.41,11025.85,11076.48,11117.75,11150.28,11174.77,11187.23,11171.31,11125.63,11048.68,10941.28,10806.35,10648.52,10473.62,10288.05,10098.27,9914.299,9737.272,9572.485,9422.993,9290.788,9176.909,9081.613,9004.543,8944.919,8901.707,8868.148,8842.356,8822.524,8807.443,8796.445,8789.339,8786.327,8787.931,8794.907,8800.899,8805.376,8813.473,8826.892,8847.135,8844.217,8829.304,8822.624,8829.472,8853.12,8895.308,8956.703,9037.268,9136.56,9253.936,9388.685,9540.127,9707.648,9890.731,10088.95,10301.99,10529.57,10771.52,11027.69,11297.96,11582.24,11880.46,12192.53,12518.37,12857.88,13210.97,13577.51,13957.37,14350.4,14756.47,15175.36,15606.93,16050.99,16507.32,16975.73,17456.01,17947.95,18451.32,18965.92,19491.55,20028,20575.09,21132.67,21700.6,22278.76,22867.09,23465.56,24074.2,24693.07,25322.31,25962.11"Min:0;Max:1"])

aux Prim_E_Castro_II = Prim_E_Castro_II_Mtoe*(41.868/1000)

aux Prim_E_Castro_II_Mtoe = GRAPH(TIME,1985,1,[7749.128,7949.405,8160.472,8369.055,8575.327,8779.441,8981.515,9181.611,9379.721,9575.755,9769.523,9960.735,10148.99,10333.8,10514.55,10690.57,10861.12,11025.39,11182.57,11331.88,11472.57,11613.07,11744.05,11868.21,11985.69,12096.8,12202.05,12302.14,12397.97,12490.61,12581.29,12667.21,12730.03,12767.88,12779.07,12764.7,12728.41,12676.04,12614.96,12553.39,12499.65,12465.21,12453.35,12470.28,12519.73,12603.9,12723.6,12878.45,13067.17,13287.84,13538.23,13805,14082.45,14367.05,14656.33,14949.01,15244.73,15543.75,15846.69,16154.27,16467.12,16785.65,17109.96,17439.79,17774.53,18113.24,18354.05,18638.35,18929.79,19227.55,19529.33,19832.11,20132.64,20427.69,20714.17,20989.24,21250.25,21494.83,21720.83,21926.33,22109.69,22269.44,22404.39,22513.53,22596.15,22651.68,22679.87,22680.64,22664.53,22677.19,22706.19,22750.75,22809.68,22881.69,22965.49,23059.8,23163.39,23275.05,23393.65,23518.01,23647.03,23779.55,23914.48,24050.72,24187.17,24322.75,24456.37,24586.99,24713.57,24835.11,24950.6,25059.11,25159.73,25251.6,25333.89,25405.85"Min:0;Max:1"])

aux Prim_E_Castro_III = GRAPH(TIME,1985,1,[7173.132,7368.388,7560.948,7750.953,7938.545,8123.845,8306.943,8487.869,8666.596,8843.009,9016.909,9188.003,9355.897,9520.108,9680.064,9835.119,9984.568,10127.67,10263.69,10391.88,10511.56,10622.13,10723.08,10814.07,10894.85,10965.43,11025.82,11074.98,11109.91,11131.53,11139.06,11127.4,11079.53,10993.89,10869.25,10707.08,10511.25,10287.46,10042.57,9783.873,9518.5,9252.879,8992.396,8741.208,8502.217,8277.143,8066.685,7870.719,7688.501,7518.869,7360.417,7209.448,7064.519,6924.253,6787.575,6653.672,6521.957,6392.023,6263.608,6136.559,6010.8,5886.309,5763.096,5641.188,5520.616,5379.155,5222.66,5064.419,4907.348,4753.312,4603.397,4458.152,4317.759,4182.184,4051.273,3924.817,3802.603,3684.433,3570.147,3459.623,3352.78,3249.571,3149.983,3054.027,2961.733,2873.143,2788.301,2707.253,2630.037,2556.684,2487.205,2421.599, 2359.843,2301.896,2247.696,2197.163,2150.199,2106.687,2066.499,2029.493,1995.519,1964.42,1936.032,1910.192,1886.735,1865.496,1846.316,1829.037,1813.511,1799.592,1787.143,1776.033,1766.143,1757.355,1749.564,1742.672"Min:0;Max:1"])

aux Prim_E_Castro_madcoal = Prim_E_Castro_madcoal_Mtoe*(41.868/1000)

aux Prim_E_Castro_madcoal_Mtoe = GRAPH(TIME,1985,1,[7727.249,7904.714,8090.315,8272.828,8453.111,8632.091,8810.723,8989.943,9170.627,9353.554,9539.376,9728.585,9921.493,10118.22,10318.67,10522.55,10729.35,10938.39,11148.8,11359.55,11569.52,11786.26,11999.63,12211.42,12420.76,12626.87,12829.17,13027.26,13220.99,13410.47,13596.08,13773.95,13924.74,14047.57,14141.5,14208.26,14251.81,14277.76,14292.74,14303.69,14317.33,14343.2,14382.91,14441.39,14521.63,14625.64,14754.65,14909.23,15089.46,15295.09,15525.66,15768.71,16021.36,16282.45,16551.25,16827.53,17111.32,17402.73,17701.79,18008.38,18322.16,18642.56,18968.79,19299.77,19634.24,19970.72,20218.39,20503.91,20792.28,21081.97,21370.64,21655.54,21933.86,22202.84,22459.86,22702.48,22928.43,23135.65,23322.28,23486.67,23627.39,23743.2,23833.11,23896.32,23932.27,23940.62,23921.26,23874.3,23810.4,23774.22,23752.98,23746.1,23752.7,23771.78,23802.33,23843.32,23893.74,23952.59,24018.87,24091.56,24169.68,24252.21,24338.13,24426.42,24516.07,24606.07,24695.39,24783.03,24868,24949.32,25026.04,25097.24,25162.02,25219.53,25268.95,25309.53"Min:0;Max:1"])

aux primary_BioE_2a_gen_EJ = IF(TIME<2011,primary_Biofuels_historic_2011_EJ,BioE_2a_gen_EJ_compet+BioE_2a_gen_EJ_marg)

aux primary_Biofuels_historic_2011_EJ = net_Biofuels_historic_2011_Gboe*5.586

aux production_EV = number_of_EV_on_the_road-number_EV_delayed

aux production_EV_delayed = DELAYINF(production_EV, 5,1,0)

doc production_EV_delayed = retardo 5 años el consumo de litio para tener en cuenta el cambio de baterias a los 5 años

aux prop_dem_CIR_without_trad_biomass = Dem_CIR_EJ_without_trad_biomass_2/Total_all_sectors

aux prop_dem_elec = Dem_elec_EJ_2/Total_all_sectors

aux prop_dem_trad_biomass = Dem_traditional_Biomass_EJ_2/Total_all_sectors

aux prop_dem_transport_after_politics = Dem_transport_after_politics_EJ_2/Total_all_sectors

aux prop_E_gen_related_losses = E_gen_related_losses_EJ_3/Total_all_sectors

aux propor_cir_coal = 1-propor_E_coal-propor_CTL_coal

aux propor_cir_gas = 1-propor_E_gas-propor_Transp_gas-propor_GTL_gas

aux propor_cir_liquids = 1-propor_E_liquids-propor_Transp_liquids

aux propor_coal_E = 1-propor_oil_E-propor_gas_E

doc propor_coal_E = [%2] Proporción (tanto por 1) de la demanda eléctrica no renovable (sin contar nucleares) cubierta por el carbón en 2007 según 5.12.

aux propor_CTL_coal = demand_coal_CTL_EJ_1/Total_demand_COAL_EJ

aux propor_E_coal = demand_coal_para_E_EJ_1/Total_demand_COAL_EJ aux propor_E_gas = demand_gas_para_E_EJ_1/Total_demand_GAS_EJ

aux propor_E_liquids = demand_liquids_para_E_1/Total_demand_Liquids_EJ

aux propor_gas_E = IF(TIME<2011,Hist_propor_gas_E,0.33)

doc propor_gas_E = Parte de la electricidad de origen no renovable (sin incluir la nuclear) cubierta por el gas natural, datos desde 1990 hasta 2008 de 5.13.

aux propor_GTL_gas = demand_gas_GTL_EJ_1/Total_demand_GAS_EJ

aux propor_i_coal = IF(TIME<2004,0.28,IF(TIME<2011,0.0075*TIME-14.7425,IF(TIME<2016,0.34,IF(TIME<2020,-0.015*TIME+30.58,0.3))))

doc propor_i_coal = IF(TIME<2004,0.28,IF(TIME<2011,0.0075*TIME-14.7425,IF(TIME<2016,0.34,IF(TIME<2020,-0.015*TIME+30.58,0.28)))) IF(TIME<2004,0.28,IF(TIME<2011,0.0075*TIME-14.7425,0.34)) Datos IEA de los años 2003 al 2007 (según 5.12) para el sector Industrial, se observa poca variación en el reparto por fuentes energéticas (con la salvedad de un aumento importante de las renovables). 0,012000x - 23,766000

aux propor_i_gas = IF(TIME<2004,0.3,IF(TIME<2011,-0.0038*TIME+7.8812,0.27))

doc propor_i_gas = IF(TIME<2005,0.30,IF(TIME<2008,-0.0120327*TIME + 24.4252421,0.275)) IF(TIME<2003,0.30,IF(TIME<2008,-0.002*TIME + 4.306,0.29)) Datos IEA de los años 2003 al 2007 (según 5.12) para el sector Industrial, se observa poca variación en el reparto por fuentes energéticas (con la salvedad de un aumento importante de las renovables).

aux propor_i_liquids = 1-propor_i_gas-propor_i_coal-propor_i_renew

doc propor_i_liquids = Datos IEA de los años 2003 al 2007 (según 5.12) para el sector Industrial, se observa poca variación en el reparto por fuentes energéticas (con la salvedad de un aumento importante de las renovables)

aux propor_i_renew = IF(TIME<2003,0.05484598,IF(TIME<2007,0.0076669*TIME - 15.3020248,0.086))

doc propor_i_renew = IF(TIME<2004,0.05484598,IF(TIME<2008,0.0076669*TIME - 15.3020248,0.086)) En el año 2007, se cubrió el 8.6% de las necesidades energéticas del sector (sin contar con la electricidad) por las renovables según 5.12.

aux propor_oil_E = IF(TIME<2011,Hist_propor_oil_E,MAX(-0.005223*TIME + 10.560631,0))

doc propor_oil_E = La proporción de OIL para electricidad lleva cayendo de forma constante en todo el mundo desde la crisis de 1973. La llevamos a 0 siguiendo la regresión con datos desde 1990 hasta 2008 de 5.13.

aux propor_pop_trad_biomass = IF(TIME<2008,0.38,MAX(-0.00444*TIME+9.29444,0.15))

doc propor_pop_trad_biomass = Disminución de la proporción de personas dependientes de la biomasa tradicional para subsistir del 36% (2008) al 25% (2035). WEO 2010.

aux propor_RC_coal = 1-propor_RC_gas-propor_RC_liquids-propor_RC_renew

doc propor_RC_coal = Datos IEA de los años 2003 al 2007 (según 5.12) para los sectores Residencial y Comercial, se observa poca variación en el reparto por fuentes energéticas.

aux propor_RC_gas = IF(TIME<2003,0.56,IF(TIME<2007,0.00976*TIME - 18.98931,0.595)) doc propor_RC_gas = Datos IEA de los años 2003 al 2007 (según 5.12) para los sectores Residencial y Comercial, se observa poca variación en el reparto por fuentes energéticas.

aux propor_RC_liquids = IF(TIME<2003,0.35,IF(TIME<2007,-0.01369*TIME + 27.76300,0.296))

doc propor_RC_liquids = Datos IEA de los años 2003 al 2007 (según 5.12) para los sectore Residencial y Comercial, se observa poca variación en el reparto por fuentes energéticas.

aux propor_Transp_gas = demand_gas_transport_EJ_1/Total_demand_GAS_EJ

aux propor_Transp_liquids = real_oil_transport_demand_1/Total_demand_Liquids_EJ

aux proportion_E_var_base_percent = Renew_var_TWh*100/(E_nr+Renew_b_TWh+Renew_var_TWh)

doc proportion_E_var_base_percent = Proporción de la energía eléctrica "variable" respecto de la total. Si ésta es demasiado importante pueden surgir problemas de gestión y de continuidad de suministro de la red de transporte. La proporción soportada será mayor cuanto mejor preparadas estén las infraestructruas (transporte, interconexiones, almacenamiento...etc). Por ejemplo, según 11.4 en UE el 50% de la energía eléctrica podría ser cubierta por eólica para el año 2050.

aux rate_renew_land = Total_surface_renew_Mha/arable_land

aux RC_after_efficiency_EJ = RC_coal+RC_gas+RC_Liquids+RC_renew

aux RC_after_renew = Residential_and_Commercial_EJ*(1-percent_saving_RC)

aux RC_coal = RC_after_renew*propor_RC_coal

doc RC_coal = Energía primaria de los sectores Residencial y Comercial cubierto por carbón.

aux RC_gas = RC_after_renew*propor_RC_gas

doc RC_gas = Energía primaria de los sectores Residencial y Comercial cubierto por gas natural.

aux RC_Liquids = RC_after_renew*propor_RC_liquids

doc RC_Liquids = Energía primaria de los sectores Residencial y Comercial cubierto por combustibles líquidos.

aux RC_renew = RC_after_renew*propor_RC_renew+RC_renew_efficiency

aux RC_renew_efficiency = Residential_and_Commercial_EJ*percent_saving_RC/2

doc RC_renew_efficiency = Energía primaria de lo sectores Residencial y Comercial cubierto por renovables. ¿multiplicar por un factor para representar el ahorro-eficiencia de energía primaria en la sustitución por EERR?)

aux real_CIR_intensity = CIR_E_demand_after_policies/GDP_S2011

aux real_Eelec_primary_intensity = (Dem_elec_EJ_2+E_gen_related_losses_EJ_3)/GDP_S2011

aux real_Etot_intensity = (dem_Prim_E_Mtoe_after_policies*41.868/1000)/GDP_S2011

aux real_I_intensity = I_after_efficiency_EJ/GDP_S2011

aux real_Oil_Transport_demand_EJ = Liquid_transport_initial_EJ-Oil_saved_by_bio_EJ-liquid_saved_EV_HEV_EJ-liquid_saved_NGV-Liquid_saved_for_E_train doc real_Oil_Transport_demand_EJ = Demanda del sector Transporte tras aplicar las políticas de ahorro-eficiencia y sustitución por coche eléctrico y tren.

aux real_RC_intensity = RC_after_efficiency_EJ/GDP_S2011

aux real_Transport_intensity = Dem_Transport_after_policies_EJ/GDP_S2011

aux Refinery_gains_EJ = (0.027)*max_extraction_H_Maggio12_oil_EJ

doc Refinery_gains_EJ = Ganancias en refinería. [WEO 2010] da una valor de 2,8 % para el 2009 y [BP 2007] de 2,6 %. Tomamos en principio 2,7 % a pesar de que ha existido una evolución desde 1980 creciente (1,9 %).

aux Renew_b_TWh = biomasa_production_TWh_2+Geot_production_TWh_3+hydro_production_TWh_3+oceanic_production_TWh_3

doc Renew_b_TWh = Producción de electricidad renovable procedente de "centrales de base" (regulares y/o regulables)

aux Renew_E_elec_propor = (E_renew_TWh/Dem_Elec_gen_TWh)*100

aux renew_electric_Prim_E_EJ = renew_electric_Prim_E_Mtoe*41.868/1000

aux renew_electric_Prim_E_Mtoe = hydro_primary_E_Mtoe_1+biomass_production_Mtoe_1+oceanic_production_Mtoe_1+geot_production_Mtoe_1+wind_production_Mtoe_1+solar_production_Mtoe_1

aux Renew_non_elec_CIR_EJ = I_renew+RC_renew

aux renew_non_electric = I_renew_1+RC_renew_1+Liquid_saved_by_bio_EJ_1

aux renew_non_electric_EJ = renew_non_electric_Mtoe*41.868/1000

aux renew_non_electric_Mtoe = renew_non_electric*(1000/41.868)+Trad_biomass_Mtoe_1

aux Renew_var_TWh = ewind_production_TWh_3+solar_production_TWh_3

doc Renew_var_TWh = Producción de electricidad renovable procedente de fuentes variables.

aux replacement_BioW = BioW_TWe/life_time_BioW

aux replacement_geot = geot_TWe*(1/life_time_geot)

aux replacement_hydro = hydro_TWe/life_time_hydro

aux replacement_oceanic = oceanic_TWe/life_time_oceanic

aux replacement_solar = solar_TWe*(1/life_time_solar)

aux replacement_wind = wind_TWe/life_time_wind

aux Residential_and_Commercial_EJ = CIR_EJ*propor_RC

doc Residential_and_Commercial_EJ = Energía primaria consumida por la suma de los sectores Residencial y Comercial (sin contar la electricidad).

aux Savings_Primary_Energy_Transport_EJ = Liquid_saved_by_E_total_EJ+Increase_E_total_EJ aux scen_2 = GRAPH(TIME,2009,1,[0.91,-1.82,-0.3,0.57,4.24,6.96,8.17,0.78,9.39,15.44,6.96,17.56,19.38,17.56,16.65,27.55,30.28,23.92,21.8,9.69,9.08,10.6,3.63,4.54,9.08,2.72,3.03,5.75,3.63,3.03,2.72,3.03,2.72,5.15,1.82,4.54,3.63,1.51,1.82,0,3.03,7.57,6.66,9.69,8.78,6.36,1.82,1.21"Min:-2;Max:35"])

aux scen_3 = GRAPH(TIME,2009,1,[-1.21,-3.94,-2.42,-5.45,0,0.61,5.45,5.45,8.48,11.5,6.96,16.35,17.56,16.65,14.53,26.04,27.55,19.98,19.07,9.69,8.78,12.11,8.48,7.57,15.44,11.2,6.06,9.69,5.45,5.75,2.72,3.94,4.54,6.06,6.06,4.54,5.75,3.33,2.72,0,3.94,7.57,6.36,9.39,0.59,7.27,1.82,0.91"Min:0;Max:1"])

aux share_land_compet_biofuels = Land_Biofuel_compet/arable_land_2

aux share_of_economy = percent_oil_non_available*economics_VC_today/GDP_today

aux share_of_jobs = percent_oil_non_available*jobs_automobile_today/jobs_world_today

doc share_of_jobs = porcentaje de los empleos posiblemente afectados por la falta de petroleo, simplemente si x barriles de produccion total dan y empleos en el sector del automovil, x porcentaje de escasez se refleja linealmente en y porcetaje de empleos, sin mas, tomando todo el petroleo mundial y el empleo del sector del automovil

aux solar_production_Mtoe = E_solar_production_EJ*(1000/41.868)

doc solar_production_Mtoe = Conversión de la producción eléctrica a Mtoe

aux surface_biomass_MHa = BioW_TWe*0

doc surface_biomass_MHa = ?

aux surface_geot_MHa = geot_TWe*0

doc surface_geot_MHa = ?

aux surface_hydro = hydro_TWe*0

doc surface_hydro = ?

aux surface_MHa_solar = solar_TWe*30

doc surface_MHa_solar = Tomando los datos de Carlos del artículo en revisión "Global solar electric power potential" y el global future average electric power density de 5 We/ha, 5 TWe ocuparían unas 100 Mha.

aux surface_MHa_wind = wind_TWe*2.6

doc surface_MHa_wind = upper value from [Fthenakis and Kim, 2009]: 3000 m2/GWh = 2.6 MHa/TWe

aux surface_oceanic = oceanic_TWe*0

doc surface_oceanic = ?

aux t_elec = TIME-2010

aux t_Icir = TIME-2007

aux t_Iransp = TIME-2015

aux Total_all_sectors = Dem_CIR_EJ_without_trad_biomass_2+Dem_elec_EJ_2+Dem_traditional_Biomass_EJ_2+Dem_transport_after_politics_EJ_2+E_gen_related_losses_EJ_3

aux total_change_E_LDV_percent = change_to_EV_percent+change_to_HEV_percent

aux total_delivered_BioE = BioLiquids_available_EJ+available_BioE_Heat_EJ

aux Total_demand_COAL_EJ = demand_coal_I_EJ_1+demand_coal_para_E_EJ_1+demand_coal_RC_EJ_1+demand_coal_CTL_EJ_1

doc Total_demand_COAL_EJ = Demanda total mundial de carbón (Industrial, Residencial, Comercial y para Electricidad).

aux Total_demand_COAL_Mtoe = Total_demand_COAL_EJ*(1000/41.868)

aux Total_demand_GAS_EJ = (demand_gas_para_E_EJ_1+demand_gas_transport_EJ_1+demand_gas_I_EJ_1+demand_gas_RC_EJ_1+demand_gas_GTL_EJ_1)

doc Total_demand_GAS_EJ = Demanda total mundial de gas natural (Industrial, Residencial, Comercial y para Electricidad).

aux Total_demand_GAS_Mtoe = Total_demand_GAS_EJ*(1000/41.868)

aux Total_demand_Liquids_EJ = demand_liquids_I_1+demand_liquids_para_E_1+demand_liquids_RC_1+real_oil_transport_demand_1

doc Total_demand_Liquids_EJ = Demanda total mundial de gas petróleo (Industrial, Residencial, Comercial y para Electricidad).

aux Total_demand_OIL_EJ = Total_demand_Liquids_EJ-Other_liquids_EJ

aux Total_demand_OIL_Mtoe = Total_demand_OIL_EJ*(1000/41.868)

aux Total_E_energy_consumption_EJ = Total_E_energy_consumption_Mtoe*(41.868/1000)

aux Total_E_energy_consumption_EJ_1 = DELAYINF(Total_E_energy_consumption_EJ,1,1,105.7)

aux Total_E_energy_consumption_Mtoe = E_gen_related_losses_Mtoe+demand_E_Mtoe_1

aux Total_electrical_losses_Mtoe = E_gen_related_losses_Mtoe+Electrical_distribution_losses_Mtoe_1

aux Total_emissions_cumulated_since_1990_GtCO2 = Total_emissions_cumulated_since_1990_GtC*11/3

aux Total_land_for_biofuels = IF(TIME<2011,primary_BioE_2a_gen_EJ*21.14,Land_Biofuel_compet+Land_biofuel_marg)

doc Total_land_for_biofuels = (biofuels1_oil_eq_Gbb)*118* 118e6 ha/Gboe de [Mediavilla2012]. hectareas por Gb de oil equivalente, de [4.15], me da el dato de 3,3 litros oil eq/ 1 ha * (1barril/159 l oil) *(1e-9Gb/b) = 2.075e-8 Gb/ha en una hectarea para etanol (sugar cane)

4.8182e+7 ha/Gb (entre 3.5e7 y 11.3e7 si tomamos el margen de bios)

Carlos da 56 MHa/Gb, tomamos 5e7 redondeando.

aux total_percent = DELAYINF(total_change_E_LDV_percent,1,1,0)

aux Total_Renew_Prim_E_EJ = Total_Renew_Prim_E_Mtoe*0.041868

aux Total_Renew_Prim_E_Mtoe = renew_electric_Prim_E_Mtoe_1+renew_non_electric_Mtoe_1

doc Total_Renew_Prim_E_Mtoe = Energía renovable total.

aux Total_surface_renew_Mha = (surface_Mha_eolic_2+Total_land_for_biofuels_2+surface_Mha_solar_2)

doc Total_surface_renew_Mha = Superficie ocupada por instalaciones renovables y biocultivos.

aux Total_TWh_production = nonRenew_E_TWh_production+E_renew_TWh_2

aux Traditional_Biomass_EJ = Traditional_Biomass_Mtoe*(41.868/1000)

aux Traditional_Biomass_Mtoe = Population_1*propor_pop_trad_biomass*(724/2.5e9)

doc Traditional_Biomass_Mtoe = Según WEO 2010 en el año 2008 había 2.5e9 personas que dependían de la biomasa tradicional con un consumo energético estimado de 724 Mtoe. Según la [AIE 2006], para el año 2030 el número de personas que aún dependerían de esta fuente de energía sería de 2.7e9.

aux Transp_energy_production_EJ = Transp_gas_production_EJ+Transp_liquids_production_EJ+Oil_saved_by_bio_EJ+E_total_Transp_EJ

aux Transp_gas_production_EJ = extraction_gas_EJ*propor_Transp_gas

aux Transp_liquids_production_EJ = (Total_demand_Liquids_EJ-Total_demand_OIL_EJ+extraction_crude_oil_EJ)*propor_Transp_liquids

doc Transp_liquids_production_EJ = CTL+GTL+Unconv. oil + refinerty gains + extraction crude oil

aux True_E_Intensity_Mtoe_TS = (extraction_total_Mtoe-extraction_total_Mtoe_delayed_3yr)/(GDP_2-GDP_delayed_3yr_2)

doc True_E_Intensity_Mtoe_TS = Intensidad energética por incrementos.

aux uranium_extracted_acuml_Kt = uranium_extract_acumul_90_EJ*1/0.419

doc uranium_extracted_acuml_Kt = Uranio extraído desde 1990.

aux WEO2012_coal_450_Scen = WEO2012_coal_450_Scen_Mtoe*(41.868/1000)

aux WEO2012_coal_450_Scen_Mtoe = GRAPH(TIME,2010,5,[3474,3521.5,3569,3074.5,2580,2337"Min:0;Max:1"])

aux WEO2012_coal_current_policies = WEO2012_coal_current_policies_Mtoe*(41.868/1000)

aux WEO2012_coal_current_policies_Mtoe = GRAPH(TIME,2010,5,[3474,3945.5,4417,4766,5115,5523"Min:0;Max:1"])

aux WEO2012_gas_450_Scen = WEO2012_gas_450_Scen_Mtoe*(41.868/1000)

aux WEO2012_gas_450_Scen_Mtoe = GRAPH(TIME,2010,5,[2740,2909,3078,3178,3278,3293"Min:0;Max:1"])

aux WEO2012_gas_current_policies = WEO2012_gas_current_policies_Mtoe*(41.868/1000) aux WEO2012_gas_current_policies_Mtoe = GRAPH(TIME,2010,5,[2740,3040.5,3341,3670,3999,4380"Min:0;Max:1"])

aux WEO2012_oil_450_Scen = WEO2012_oil_450_Scen_Mtoe*(41.868/1000)

aux WEO2012_oil_450_Scen_Mtoe = GRAPH(TIME,2010,5,[4113,4197.5,4282,4095,3908,3682"Min:0;Max:1"])

aux WEO2012_oil_current_policies = WEO2012_oil_current_policies_Mtoe*(41.868/1000)

aux WEO2012_oil_current_policies_Mtoe = GRAPH(TIME,2010,5,[4113,4327.5,4542,4698.5,4855,5053"Min:0;Max:1"])

aux WEO2012_Prim_E_450_Scen = WEO2012_Prim_E_450_Scen_Mtoe*(41.868/1000)

aux WEO2012_Prim_E_450_Scen_Mtoe = GRAPH(TIME,2010,5,[12730,13453,14176,14314.5,14453,14793"Min:0;Max:1"])

aux WEO2012_Prim_E_current_policies = WEO2012_Prim_E_current_policies_Mtoe*(41.868/1000)

aux WEO2012_Prim_E_current_policies_Mtoe = GRAPH(TIME,2010,5,[12730,14031,15332,16415.5,17499,18676"Min:0;Max:1"])

aux WEO2012_renew_450_Scen = WEO2012_renew_450_Scen_Mtoe*(41.868/1000)

aux WEO2012_renew_450_Scen_Mtoe = GRAPH(TIME,2010,5,[1684,1996.5,2309,2817.5,3326,3925"Min:0;Max:1"])

aux WEO2012_renew_current_policies = WEO2012_renew_current_policies_Mtoe*(41.868/1000)

aux WEO2012_renew_current_policies_Mtoe = GRAPH(TIME,2010,5,[1684,1915,2146,2328,2510,2702"Min:0;Max:1"])

aux WEO2012_TWh_450_Scen = GRAPH(TIME,2010,5,[21408,23952.5,26497,28169,29841,31748"Min:0;Max:1"])

aux WEO2012_TWh_current_policies = GRAPH(TIME,2010,5,[21408,25301,29194,32843,36492,40364"Min:0;Max:1"])

aux wind_production_Mtoe = E_wind_production_EJ*(1000/41.868)

doc wind_production_Mtoe = Conversión de la producción eléctrica a Mtoe

const a_Ecir_intensity_evolution = 0.995

const a_Etransp_intensity_evolution_2015 = 0.9932979819

doc a_Etransp_intensity_evolution_2015 = 0.9932979819 1-0.0087 Esta variable contiene el valor del parámetro a de la intensidad energética del sector transporte a partir del 2005 (el histórico es: 0.9932979819). I(t) = a * I(t-1). Si suponemos una mejora adicional del 0.25% anual, entonces tendremos que poner: 0.9907979819.

const abundance_oil2 = 1

doc abundance_oil2 = Gb de petroleo que sobran o faltan

const arable_land = 1526

doc arable_land = 1526 MHa según faostat const arable_land_2 = 1526

doc arable_land_2 = Mha Hectáreas de tierras arables y con cultivos permamentes en el mundo [Faostat 2007].

const BioE_to_heat = 0.8

doc BioE_to_heat = for electricity: 0.3 [Carlos&Carpintero]. 80% es valor habitual.

const Biofuels_liquid_saved_for_bio_Mtoe = 0

const biomasa_production_TWh_2 = 0

const biomass_production_E_Mtoe_2 = 0

const biomass_production_Mtoe_1 = 0

const bioW_production_TWh_2 = 0

const Conv_EJ_EJ = 0.15

const conv_MHa_EJ = 0.0488808

doc conv_MHa_EJ = From [Mediavilla2013]: 118 Gboe/MHa = 0.047305 EJ/MHa

const copper_production_today = 15e9

doc copper_production_today = Kg de produccion de cobre aprox 2005 (wiki)

const copper_reserves = 940e9

doc copper_reserves = Kg de cobre reserva base recuperable economicamente segun wiki y US Geographical Survery

const cost_energy_biomass_2 = 0

const cost_energy_eolic_2 = 0

const cost_energy_geot_2 = 0

const cost_energy_hydro_2 = 0

const cost_energy_oceanic_2 = 0

const cost_energy_solar_2 = 0

const CTL_and_GTL_EJ_1 = 0

doc CTL_and_GTL_EJ_1 = Coal to Liquids. IEO 2010 (datos de 2010). Carlos lo trata como petróleo no convencional, ¿no debería de sustraerse de las reservas de carbón con una eficiencia energética? p.112 tesis

const CTL_efficiency = 0.45

doc CTL_efficiency = [IPCC2007] Mitigation III da 37-50% para las actuales tecnologías y hasta 67% para las futuras.

const delivered_BioE_Electricity_EJ_1 = 0 const Dem_elec_EJ_2 = 0

const Dem_Elec_gen_TWh_1 = 0

const dem_Prim_E_Mtoe_after_politics_1 = 0

const dem_Primary_energy_Mtoe_after_politics_1 = 0

const Dem_traditional_Biomass_EJ_1 = 0

const Dem_traditional_Biomass_EJ_2 = 0

const dem_Transport_after_policies_EJ_1 = 0

const Dem_transport_after_politics_EJ_2 = 0

const demand_coal_CTL_EJ_1 = 0

const demand_coal_I_EJ_1 = 0

const demand_coal_para_E_EJ_1 = 0

const demand_coal_RC_EJ_1 = 0

const demand_E_Mtoe_1 = 0

const demand_gas_GTL_EJ_1 = 0

const demand_gas_I_EJ_1 = 0

const demand_gas_para_E_EJ_1 = 0

const demand_gas_RC_EJ_1 = 0

const demand_gas_transport_EJ_1 = 0

const demand_liquids_I_1 = 0

const demand_liquids_para_E_1 = 0

const demand_liquids_RC_1 = 0

const E_coal_production_TWh_1 = 0

const E_gas_production_TWh_1 = 0

const E_gen_related_losses_EJ_2 = 0

const E_losses_gas_Mtoe_1 = 0

const E_losses_nuclear_Mtoe_1 = 0

const E_losses_oil_Mtoe_1 = 0

const E_oil_production_TWh_1 = 0

const E_renew_TWh_2 = 0

const E_TWh2 = 0

const economics_VC_today = (1.9e12*1.4)/1e12

doc economics_VC_today = Segun OICA 1.9 trillion euros son los turnover (beneficios?) de la industria del automovil a nivel mundial. Esto son 1.9 millones de millones = 1.9 e 12 euros, multiplico por 1.4 para hallar dolares, o mas bien T$.

const efficiency_coal_1 = 0

const efficiency_gas_1 = 0

const efficiency_nuclear = 1/3

doc efficiency_nuclear = Eficiencia (mundial) de las centrales nucleares [IEA Key Stats].

const efficiency_oil = 1/3

doc efficiency_oil = Eficiencia (mundial) de las centrales de petróleo. De momento pongo 1/3 porque tengo dificultades para calcular la exacta.

const electric_renewables_emissions = 0

const ewind_production_TWh_3 = 0

const ext_oil2 = 0

const extra_MHa_compet = 100

const extraction_total_EJ_2 = 0

const extraction_uranium_Mtoe_1 = 0

const GDP_1 = 0

const GDP_2 = 0

const GDP_3 = 0

const GDP_delayed_3yr_2 = 0

const GDP_today = 60

doc GDP_today = GDP en 2010 mas o menos, 60T$

const geot_production_Mtoe_1 = 0

const geot_production_TWh_2 = 0

const Geot_production_TWh_3 = 0

const GtC_limit_2C_stabilization = 1000

doc GtC_limit_2C_stabilization = "Total anthropogenic emissions of one trillion tonnes of carbon (3.67 trillion tonnes of CO2), about half of which has already been emitted since industrialization began, results in a most likely peak carbon-dioxideinduced warming of 2 6C above pre-industrial temperatures, with a 5–95% confidence interval of 1.3–3.9 6C." [Allen2009], [Meinshausen2009]

const GtCO2e_geot_1 = 0

const GtCO2e_hydro_1 = 0

const GtCO2e_oceanic_1 = 0

const GtCO2e_solar_1 = 0

const GtCO2e_wind_1 = 0

const GTL_efficiency = 0.55

doc GTL_efficiency = [IPCC2007] Mitigation III

const Hist_CTL = 0.034

const Hist_GTL = 0.05

const Historical_a_cir_E_intensity = 0.995

doc Historical_a_cir_E_intensity = Cálculo del parámetro "a" anual en el periodo 1990-2010: a=I(t)/I(t-1). Calculado en Investigación - Bibliografia\Socioeconomic inputs e Intensidades/GDP_Pop_intensities inputs.xlsx

const hydro_primary_E_Mtoe_1 = 0

const hydro_production_TWh_2 = 0

const hydro_production_TWh_3 = 0

const I_renew_1 = 0

const Icir_2007 = 3.25

doc Icir_2007 = Itot en el año inicial (2007). en Investigación - Bibliografia\Socioeconomic inputs e Intensidades/GDP_Pop_intensities inputs.xlsx

const Ielec0_2010 = 290

doc Ielec0_2010 = Itot en el año inicial (2010). en Investigación - Bibliografia\Socioeconomic inputs e Intensidades/GDP_Pop_intensities inputs.xlsx

const Increase_Elec_total_TWh_1 = 0

doc Increase_Elec_total_TWh_1 = Incremento de demanda eléctrica debido a la transición de petróleo a electricidad (transporte "eléctrico" de personas y mercancías - coche eléctrico, potenciación del tren...)

const invest_biofuels_Tdolar_2 = 0

const invest_biomass_Tdolar_2 = 0

const invest_geot_Tdolar_2 = 0

const invest_hydro_Tdolar_2 = 0

const invest_oceanic_Tdolar_2 = 0

const invest_solar_Tdolar_2 = 0

const Itransp_2015 = 1.485

doc Itransp_2015 = Itot en el año inicial (2005). en Investigación - Bibliografia\Socioeconomic inputs e Intensidades/GDP_Pop_intensities inputs.xlsx

const jobs_automobile_today = 8e6

doc jobs_automobile_today = Segun OICA 8e6 jobs directos en la industria del automovil y auxiliales (8,4e6 maneja la OIT), pero estiman que indiretamente son 50e6.

const jobs_world_today = 160e6

doc jobs_world_today = Segun OICA 8e6 jobs directos en la industria del automovil y auxiliales (8,4e6 maneja la OIT), pero estiman que indiretamente son 50e6.

const K_liquid_E_EV_TWh_EJ = 95

doc K_liquid_E_EV_TWh_EJ = [Mediavilla2012] da 530 TWh/Gboe = 95 TWh/EJ de [EABEV 2008]--------Según 4.15 el factor saldría de 52,6 TWh/EJ (consumo de un coche eléctrico medio 3 MWh/año suponiendo 15.000 km). 32,25 TWh/EJ (180 TWh/Gb) calculado por Marga, factor de intercambio entre oil y E, basado en las necesidades comparadas de transporte con coche eléctrico (que no sé si es extrapolable a otros tipos de transporte). Sacado de suponiendo 103 litros de combustibles. liquidos por cada barril de petroleo, 0.07 l/Km, y 0.137 KWh/km

const K_liquid_E_train_TWh_EJ = 69.43

doc K_liquid_E_train_TWh_EJ = 69,43 TWh/EJ de la"Propuesta ecologista de generación eléctrica para 2020" de Ecologistas en Acción (2011), a falta de constrastar con otros datos.

const km_yr_average_car = 20000

doc km_yr_average_car = Km que recorre al año un coche medio, Israel toma 20000, PPP 13333, cambia bastante de uno a otro

const life_time_BioW = 40

const life_time_geot = 40

const life_time_hydro = 100

const life_time_nuclear_40 = 40

const life_time_oceanic = 50

const life_time_solar = 25

const life_time_wind = 25

const Liquid_saved_by_bio_EJ_1 = 0

const Liquid_saved_by_bio_EJ_2 = 0

doc Liquid_saved_by_bio_EJ_2 = en EJ, 5,71 EJ por Gbarril

const liters_per_barrel = 103

doc liters_per_barrel = litros de gasolina o gasoil por barril de petroleo 103 toma PPP 159 Israel const Max_BioE_residues = 25

doc Max_BioE_residues = Potencial según [WBGU2008] en tierras no cultivadas actualmente

const max_extraction_ASPO_oil_EJ = GRAPH(0,0,600,[0,29.97832,46.74028,59.49534,71.36029,84.93571,96.09971,107.4647,118.4603,127.5374,137.0181,145.8883,152.0052,156.2876,162.4698,166.6593,171.044"Min:0;Max:180;Zoom"])

doc max_extraction_ASPO_oil_EJ = Curva ASPO de extracción de oil hasta 2050. Unidades: EJ. Para los puntos a partir del 2050 se ha realizado una exponencial negativa hasta anular las reservas en 2100.

const max_extraction_gas_Mohr_BG2013 = GRAPH(0,0,1000,[0,27.4739,42.1041,51.2745,58.1215,69.3726,79.5334,99.1636,115.575,128.798,138.387,147.465,150.753,157.008,159.247,159.247,159.247,159.247,159.247,159.247,159.247"Min:0;Max:200;Zoom"])

doc max_extraction_gas_Mohr_BG2013 = Curva MohrBG2013 de extracción de gas hasta 2100. Unidades: EJ.

const max_extraction_gas_Mohr_High2013 = GRAPH(0,0,1500,[0,36.4477,58.3656,72.8198,98.5,130.439,159.979,177.268,190.383,194.052,194.197,194.197,194.197,194.197,194.197,194.197,194.197,194.197,194.197,194.197"Min:0;Max:200;Zoom"])

doc max_extraction_gas_Mohr_High2013 = Curva Mohr High case 2013 de extracción de gas hasta 2100. Unidades: EJ.

const max_geot_TWe = 0.22

doc max_geot_TWe = 0.22 Techo de generación geotérmico eléctrico según Carlos de Castro.

const max_hydro_TWe = 0.7

doc max_hydro_TWe = [TWe] 0.7 Potencia máxima que se puede extraer de energía hidroeléctrica anualmente, no consumo en TWh), sino TWe según Carlos de Castro.

const max_lith_extr_today = 200e6

doc max_lith_extr_today = segun 4.1 PPP 16 e6 Kg de litio extraídas actualmente

segun ETC 4.7 produccion actual de litio 25e6 Kg/yr en 2007, anque también dicen que la demanda es menor es 17,5e6Kg/yr en 2009 (¿?) Se dice que puede aumentar a 50 en 2010?? maxima capacidad de extraccion en estos años 200e6 Kg/yr buscar dato actual??

const max_oceanic_TWe = 0.5

doc max_oceanic_TWe = Potencia máxima que se puede extraer de energía oceánica anualmente según Carlos de Castro.

const Max_percent_saving_I = 0.5

doc Max_percent_saving_I = Techo de ahorro en el sector Industrial (en tanto por 1).

const Max_percent_saving_RC = 0.5

doc Max_percent_saving_RC = Techo de ahorro en los sectores Residencial y Comercial (en tanto por 1).

const max_solar_TWe = 3

doc max_solar_TWe = Potencia máxima que se puede extraer de energía solar anualmente según Carlos de Castro.

const Max_unconv_oil = 10000*5.582

doc Max_unconv_oil = 10 Gb por poner algo = 10*1000/365 = 27.4 Mb/d . En [Carlos 2009] la contribución de los unconventional es < 10 Gb anuales en 2045.

const max_wind_TWe = 1

doc max_wind_TWe = 1.25 Potencia máxima que se puede extraer de energía eólica anualmente según Carlos de Castro.

const nuclear_emissions = 0

const Nuclear_production_TWh_1 = 0

const number_CV_today = 806e6

doc number_CV_today = numero de vehiculos convencionales en el mundo 2010 coches y vehiculos ligeros (solamente, camiones y buses no).

const oceanic_production_Mtoe_1 = 0

const oceanic_production_TWh_2 = 0

const oceanic_production_TWh_3 = 0

const Oil_saved_for_E2 = 1

const P_BioE_2a_gen = 0.08

const P_BioE_3a_gen = 0.08

doc P_BioE_3a_gen = 0.2

const P_GDPcap = 0.019

doc P_GDPcap = Evolución el GDP a partir del año 2010. Según los datos del WorldBank, en el periodo 1960-2011 el crecimiento del GDPpc MER fue del 1.9% anual de media.

const P_nuclear_2_3 = 1

doc P_nuclear_2_3 = Si P_nuclear = 0 --> escenario 2. P_nuclear = 1 --> escenario 3 (PLEX)

const P_nuclear_scen_1 = 0

doc P_nuclear_scen_1 = Si P_nuclear_1 = 0 --> escenario 1.
P_nuclear_1 = 1 --> permito los escenarios 2 y 3 (PLEX)

const P_nuclear_scen_4 = 0

doc P_nuclear_scen_4 = Si P_nuclear_1 = 1 --> escenario 4.
P_nuclear_1 = 0 --> permito los escenarios 1 (cte), 2 y 3 (PLEX)

const P_residues = 0.08

const P1_CTL = 0.15

const P1_GTL = 0.15

const P1_L_Ex = 1

doc P1_L_Ex = si P1_L_Ex es igual a 1 tenemos policy lineal si es 0 tenemos policy exponencial.

const P1_L_Ex_HEV = 1

doc P1_L_Ex_HEV = si P1 L Ex es igual a 1 tenemos policy lineal si es cero tenemos policy exponencial.

const P1_L_Exp_I = 1

doc P1_L_Exp_I = si P1_L_Ex es igual a 1 tenemos policy lineal si es 0 tenemos policy expon1encial.

const P1_L_Exp_RC = 1

doc P1_L_Exp_RC = si P1_L_Ex es igual a 1 tenemos policy lineal si es 0 tenemos policy expon1encial.

const P1_solar = 0.15

doc P1_solar = +19 % (1990-2010), +5.5% (1990-2000), +34% (2000-2010) según [tonto.eia]. Para compensar la depreciación: +8.7% 0.15

const P1_unconv_oil = 0.045

const P1_wind = 0.20

const P2 = 0

doc P2 = a partir de 2011 policy lineal, cada año cambiamos un P2 el factor change_to_E_percent_train que esta entre 0 y 1. De momento he puesto 0,0033 (un tercio que para el coche eléctrico) por poner algo.

const P2_L_Ex = 1

doc P2_L_Ex = si P1_L_Ex es igual a 1 tenemos policy lineal si es 0 tenemos policy exponencial.

const past_BioW = 0.07

doc past_BioW = 6.4 % (1990-2010) según [tonto.eia]. Pero como ya se nota el efecto de la saturación, lo aumentamos hasta que coincida con los valores históricos.

const past_geot = 0.032

doc past_geot = 3.2 % según [tonto.eia] para el periodo 1990-2010.

const past_hydro = 0.042

doc past_hydro = el crecimiento anual medio 1990-2010 fue +2.33% anual [EIAdb]. Pero, como nos encontramos relativamente cerca del máximo, tenemos que poner un valor de "past_hydro" mayor hasta que coincide la producción histórica para el año 2010.

const past_oceanic = 0

doc past_oceanic = 0

const past_solar = 0.187

doc past_solar = +19 % (1990-2010), +5.5% (1990-2000), +34% (2000-2010) según [tonto.eia]. Para compensar la depreciación: +21.11%

const past_wind = 0.258

doc past_wind = +25.7 % (1990-2010), +24.5% (1990-2000), +27% (2000-2010) según [tonto.eia]. Para compensar la depreciación tenemos que poner un crecimiento mayor: +26.4%

const Population_1 = 0

const pre_industrial_value_ppm = 275

const propor_E = 0.01

const propor_gas_losses = 0.026

doc propor_gas_losses = In IEA statistics, "natural gas to transport" includes several losses such as "pipeline transport, other transformation" (IEA ETP 2012).

const propor_industrial = 0.75

doc propor_industrial = Tomando los datos por sectores de la IEA de los años 2003 al 2007 [5.12] la proporción no cambia apenas. (Además el [WEC 5.14] en sus previsiones tampoco varía el peso de los sectores)

const propor_RC = 0.25

doc propor_RC = Tomando los datos por sectores de la IEA de los años 2003 al 2007 (según 5.12) la proporción no cambia apenas. (Además el WEC (5.14) en sus previsiones tampoco varía el peso de los sectores)

const propor_RC_renew = 0.01

doc propor_RC_renew = En el año 2007, se cubrió el 1% de las necesidades energéticas del sector (sin contar con la electricidad) por las renovables según 5.12

const Propr_electrical_distribution_losses = 0.09

doc Propr_electrical_distribution_losses = Mayoramos la electricidad demandada en un 8% debido a las pérdidas por transporte mundiales (5.15).

const RC_renew_1 = 0

const real_oil_transport_demand_1 = 0

const renew_electric_Prim_E_Mtoe_1 = 0

const renew_non_electric_Mtoe_1 = 0

const solar_production_Mtoe_1 = 0

const solar_production_TWh_2 = 0

const solar_production_TWh_3 = 0

const surface_Mha_eolic_2 = 0

const surface_Mha_solar_2 = 0

doc surface_Mha_solar_2 = Las central termoeléctrica de La Florida ocupaba 0,5e6m2 para 50MW, tomamos este dato aunque el de la eolica es menor. Esto son 50ha/MW, es decir 50e6 ha/TW. y pasamos de hectareas a Ma, Ma=e8 Ha

const Total_land_for_biofuels_2 = 0

const Trad_biomass_Mtoe_1 = 0

const Trad_biomass_Mtoe_2 = 0

const TRE_bioW = 1

doc TRE_bioW = ?

const TRE_geot = 10

doc TRE_geot = Según [38], [39] Existen diferentes estudios, y además existe variación en función del tipo: 11.6: 2.4,12.39.

const TRE_hydro = 15

doc TRE_hydro = Según [38], [39]. Existen diferentes estudios. (11.5: 20-40, 11.6: 11.2).

const TRE_oceanic = 1

doc TRE_oceanic = Sin datos (de momento)

const TRE_solar = 10

doc TRE_solar = Existen diferentes estudios. Según [38], [39] (11.5: 5-25, 11.6: 1.7-10).

const TRE_wind = 30

doc TRE_wind = Según [38], [39] Según 11.5: 20-40.

const urban_surface_2008 = 300

doc urban_surface_2008 = La superficie urbana ocupada en 2008 se estima entre unos 200-400 Mha (Carlos). Lo pongo para comparar órdenes de magnitud.

const VE_objetive_UE2020 = 1

const VE_objetive_UE2020_extrap = 1

const wind_production_Mtoe_1 = 0

const wind_production_TWh_2 = 0