# *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).
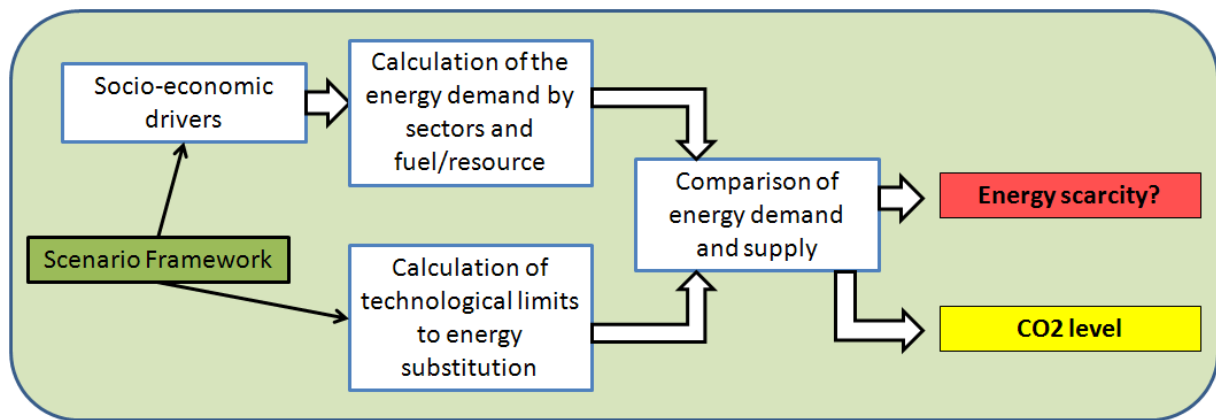


**Figure 1: Basic logic functioning of the WoLiM model.**

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).

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[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, $CO_2$ 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)).
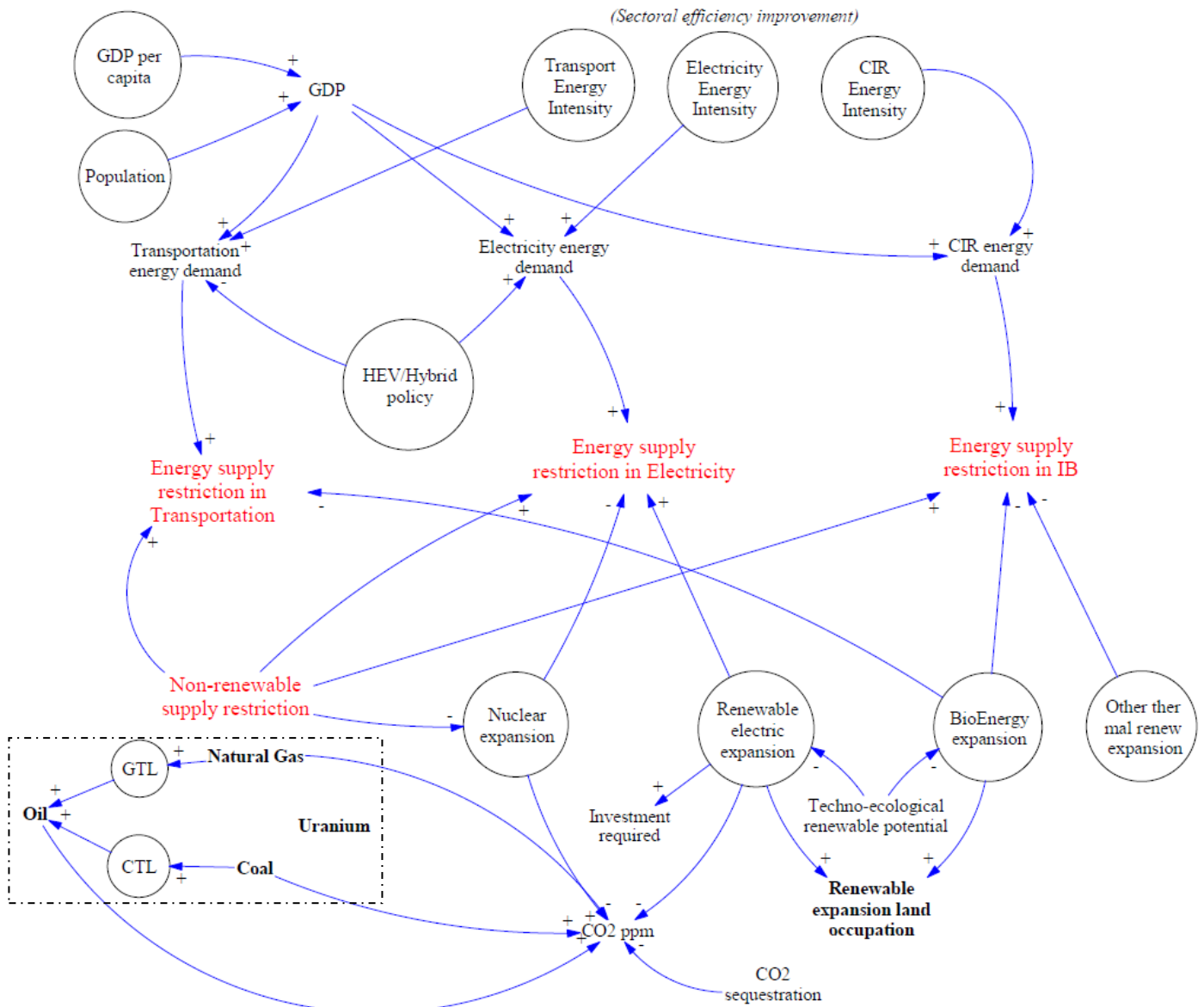
**Figure 2:** **Causal loop diagram of the model WoLiM 1.0 with its basic elements. Scenario elements and policies are circled. IB  Industrial and Buildings sectors.**

## 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).
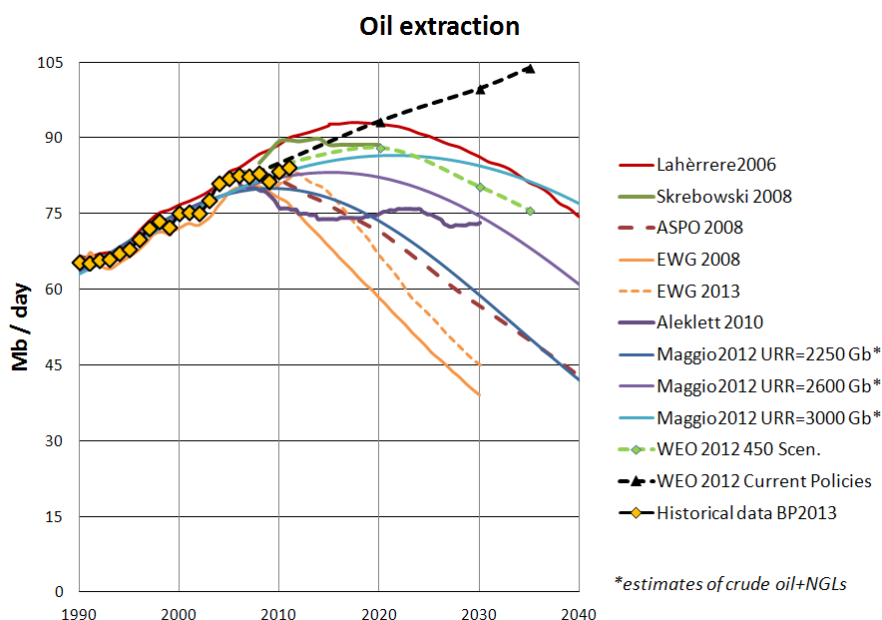


**Figure 3: Estimations of oil extraction by different authors. There is a lack of standardization in the literature. For each study, "oil" refers to only crude oil (including NGLs) (Maggio and Cacciola, 2012); crude and unconventional (ASPO, 2009; EWG, 2013, 2008); crude, unconventional and refinery 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

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[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.
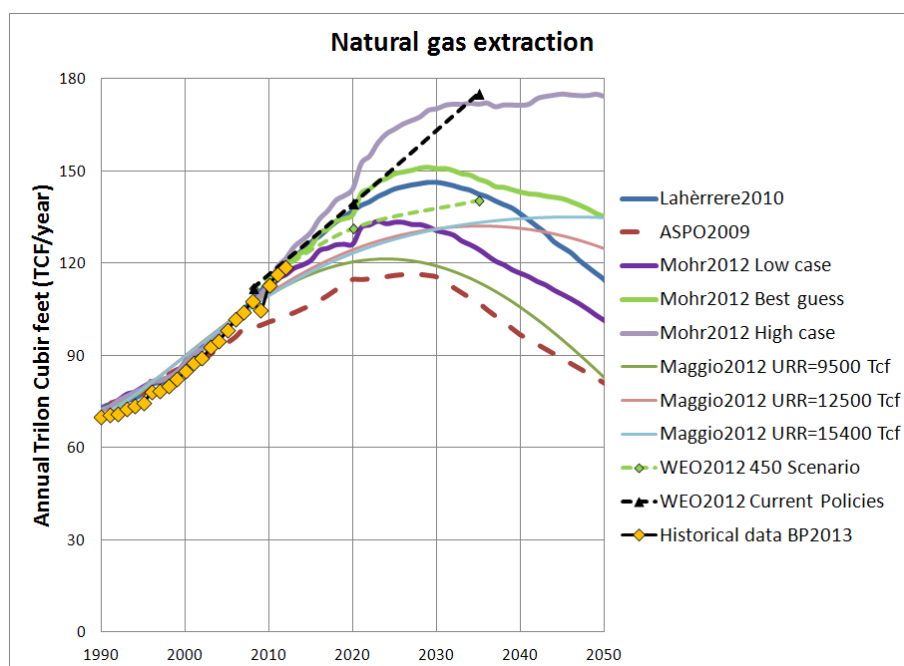


**Figure 4: Estimations of conventional and unconventional natural gas extraction by different authors**

### 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.

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[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).
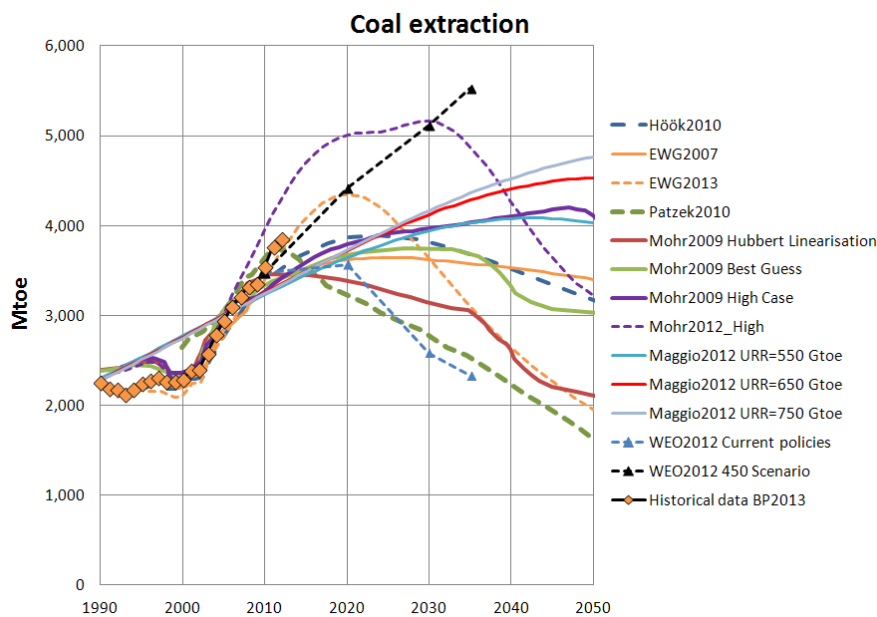


**Figure 5: Estimations of coal extraction by different authors. (1 Mt = 0.482 Mtoe (Höök et al., 2010)).**

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.**

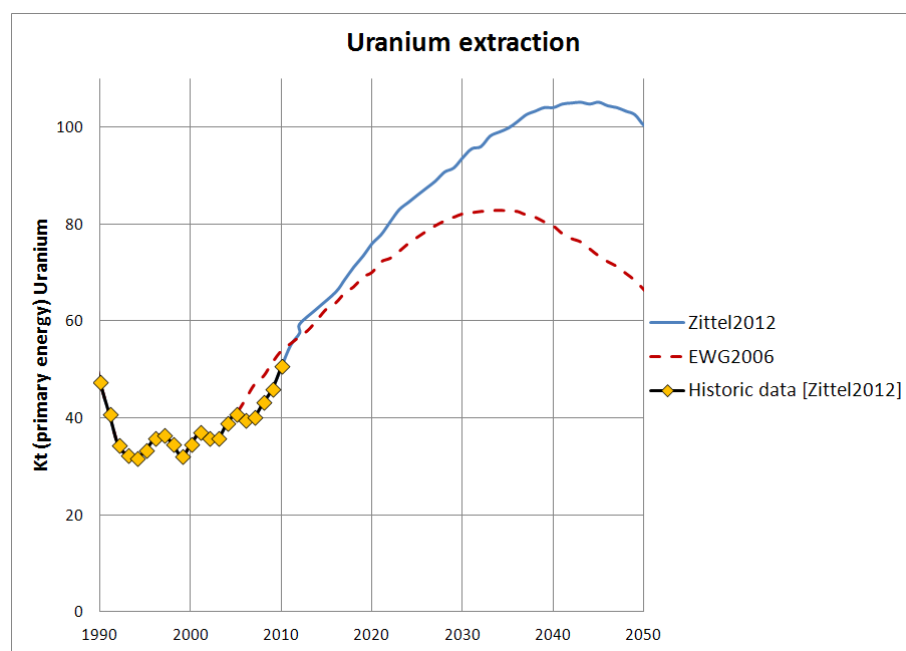| Resource | | Reference | Description | URR | |
|---|---|---|---|---|---|
| Oil | Conv. | (Maggio and Cacciola, 2012) middle scenario. | Hubbert method. | 2,600 Gb | 14.5 ZJ |
| | Unconv. | *Best Guess:* Own projection based on (de Castro et al., 2009) | Extrapolation of past trends deployment (+ 4.5 %/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*

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[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).

*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.

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 improvably 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.

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[8] When the parameter abundance goes below 0 (see section 5).
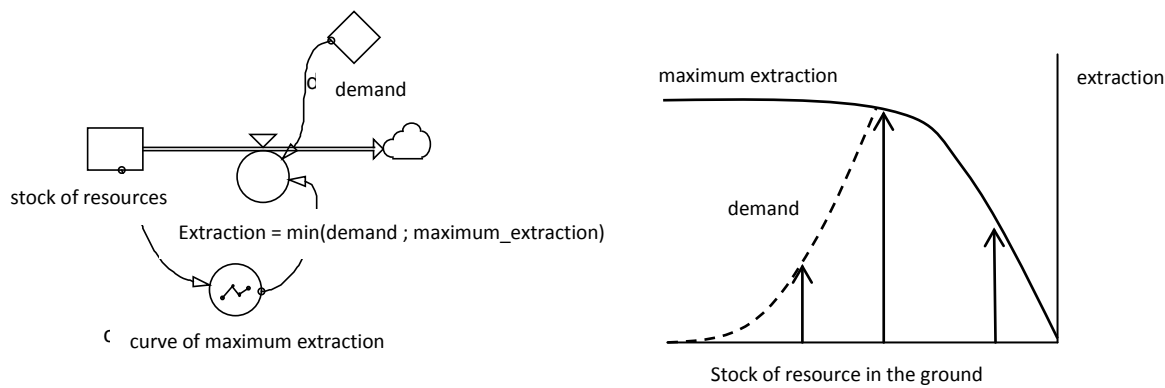
**Figure 7 (Mediavilla et al., 2013): Maximum extraction curves as a function of resources. Left: the systems dynamics model used to model extraction. Right: a curve of maximum extraction (solid) compared with the demand (dashed). Both curves meet when the peak of the resource is reached.**

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.
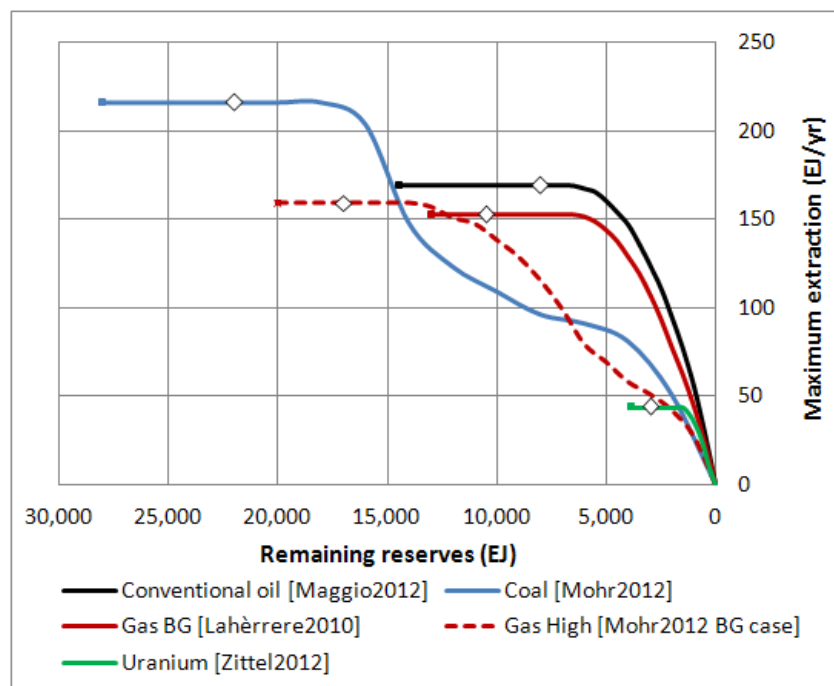


**Figure 8: Curves of maximum extraction in function of the remaining reserves for all the non-renewable resources (Primary Energy). The y axis represents the maximum achievable extraction rate (EJ per year) associated to the remaining reserves (EJ). For each resource, the extreme left point (that coincides 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.

<u>Bioenergy</u>

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., | 386 | 0.033[a] | 4.1 (gross power) |

| | | | 2008) | | |
|---|---|---|---|---|---|
| | 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).

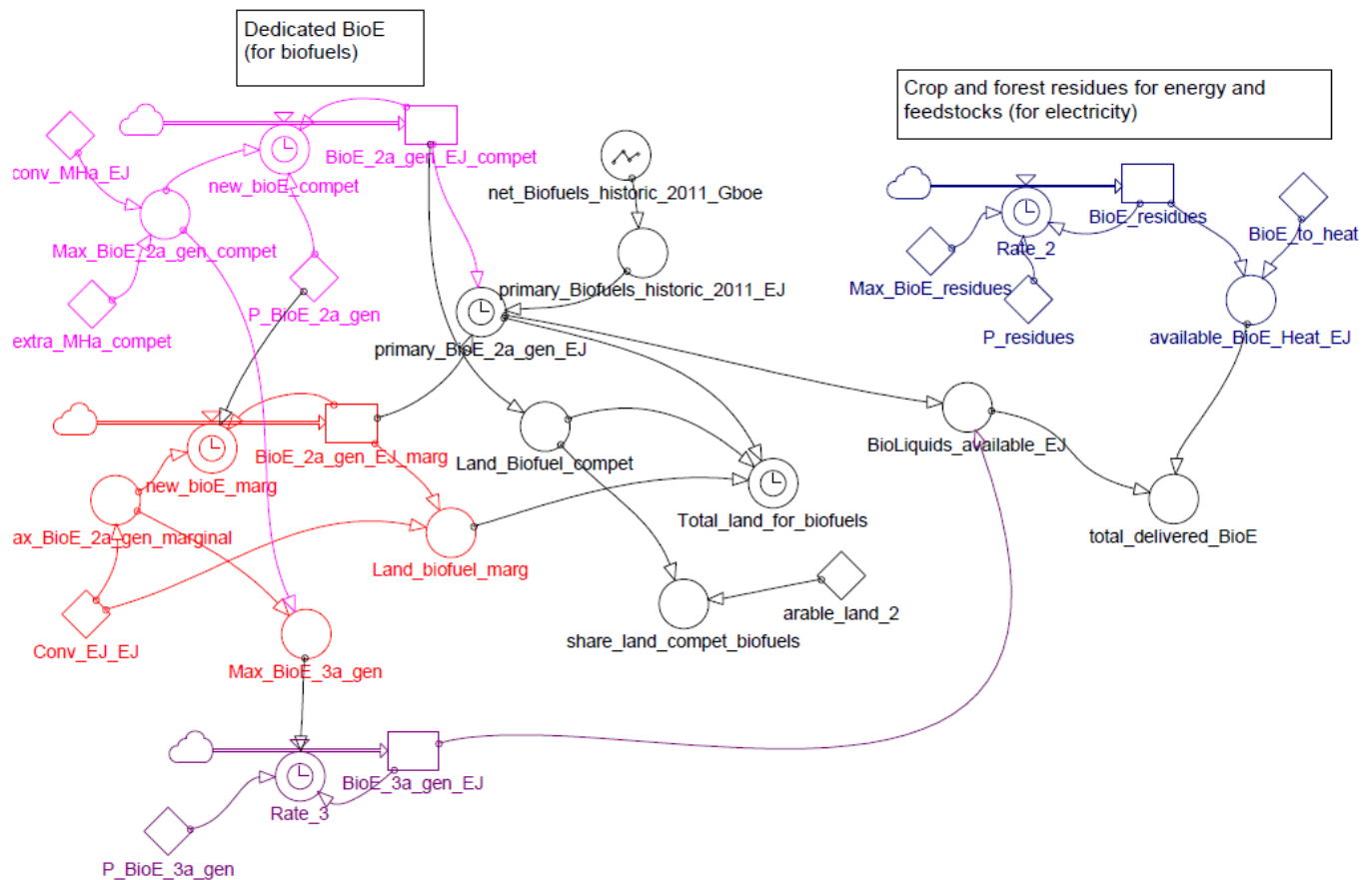The Forrester diagram of the modeling is shown in the **Figure 9**.

**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)**:

$$ \text{equation (1)} $$

**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**)):

$$ \text{equation (2)} $$

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.
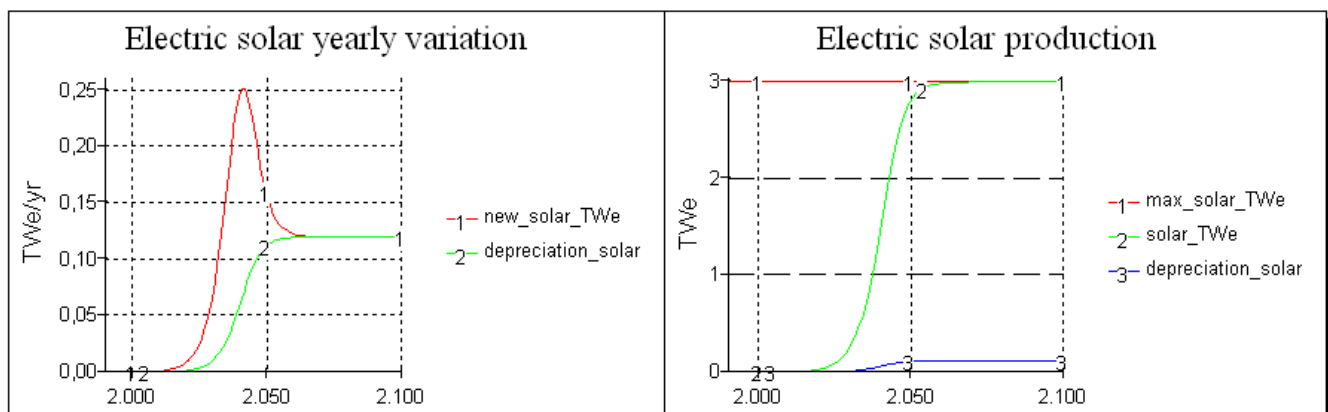
**Figure 10: a) New solar electric production and depreciation by year (TWe/yr); b) Total electric solar production (TWe). In this figure we represent the dynamics of equation 1 considering a very rapid growth of solar (+30%, as in scenarios 2 and 4). While being far from the potential limit, exponential 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**):
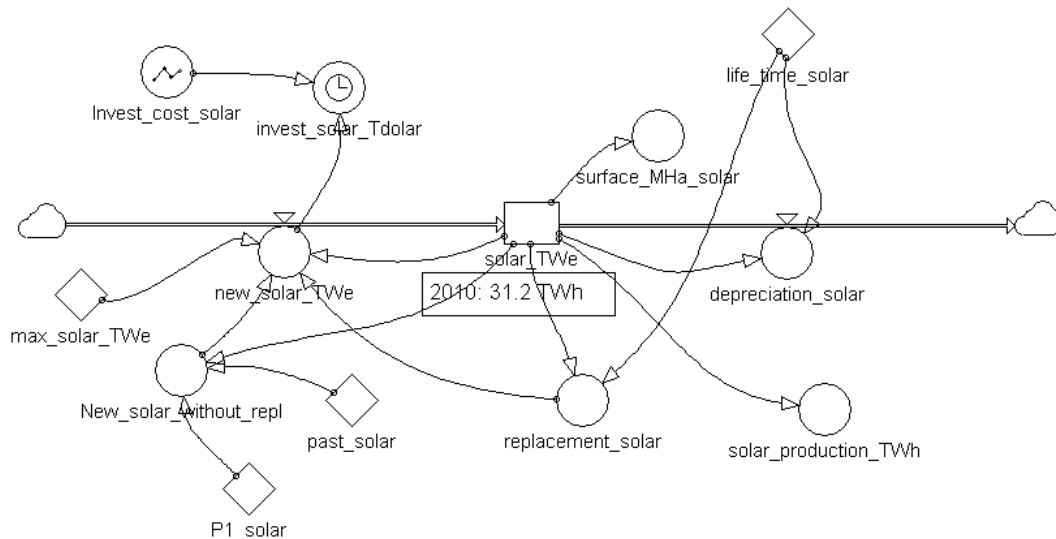


**Figure 11: Structure of the renewable electric technologies. Here, we represent solar.**

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 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 |

---

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

| | |
|---|---|
| 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:

<div align="right">equation (3)</div>

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 ($I_{t-1}$):

<div align="right">equation (4)</div>

<div align="right">equation (5)</div>

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.

---

[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.

The results of the sectoral energy intensity regressions are shown in Table 6 and Figure 12.

| Energy sector | Sectoral Energy Intensities | | Period |
|---|---|---|---|
| Total PE demand | ($R^2$=0.999840) | EJ / US$ | 1971-2010 (regression) |
| Transport PE demand | ($R^2$=0.999841) | EJ / US$ | 1971-2007 (regression) |
| Electricity generation | ($R^2$=0.999916) | TWh/ US$ | 1980-2010 (regression) |
| IB PE demand | | 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).**
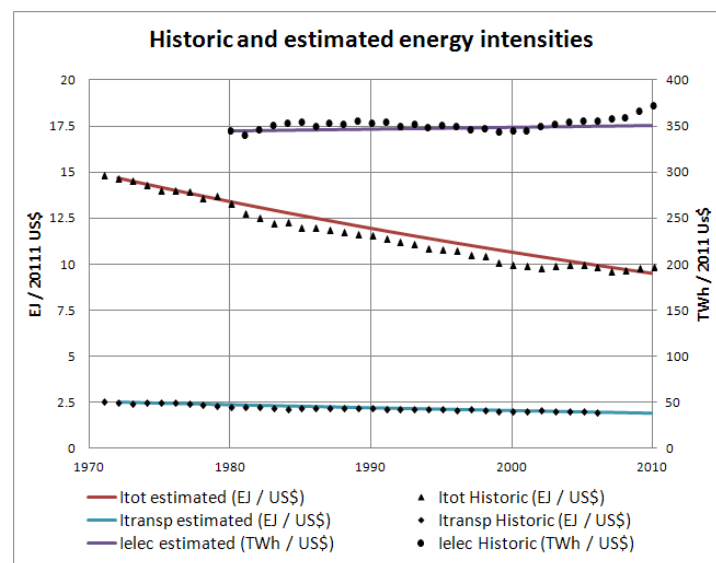


**Figure 12: Historic and estimated energy intensities by sectors. Itot refers to Total Energy Primary intensity (EJ/US$), Itransp to Transportation intensity (EJ/US$), and Ielec to Electrical generation intensity (TWh/US$). All dollars in the paper are in 2011 US$.**

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 10 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 350 TWh/2011 US$ due to the massive transition of more developed economies to that (more efficient) source of energy (Fouquet, 2010).

<u>Energy intensity scenario implementation</u>

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):

$$\text{equation (6)}$$

*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.

<u>Application of the Energy Intensity as physical indicator</u>

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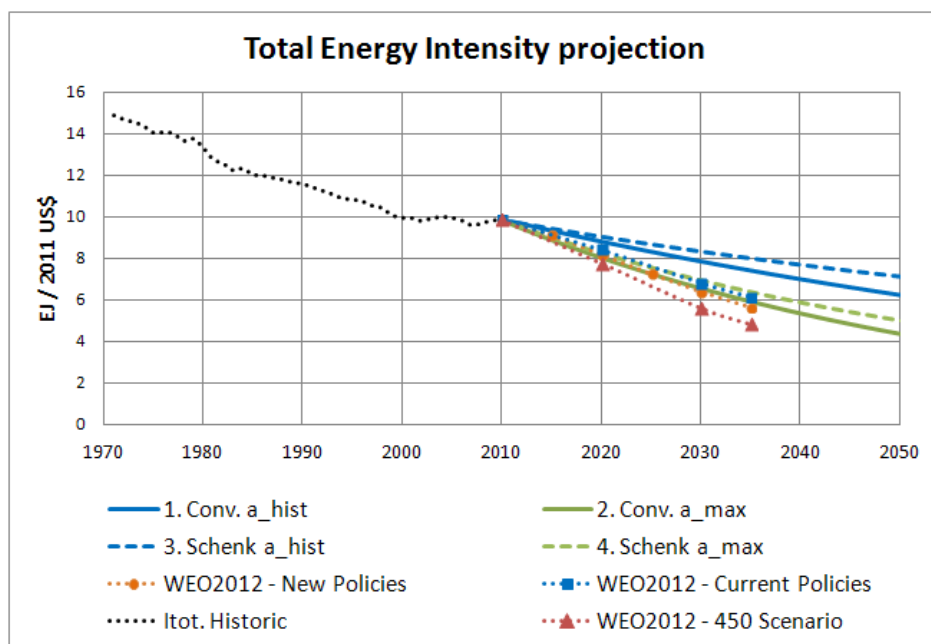
**Figure 13: Application of the Energy Intensity as physical indicator.**

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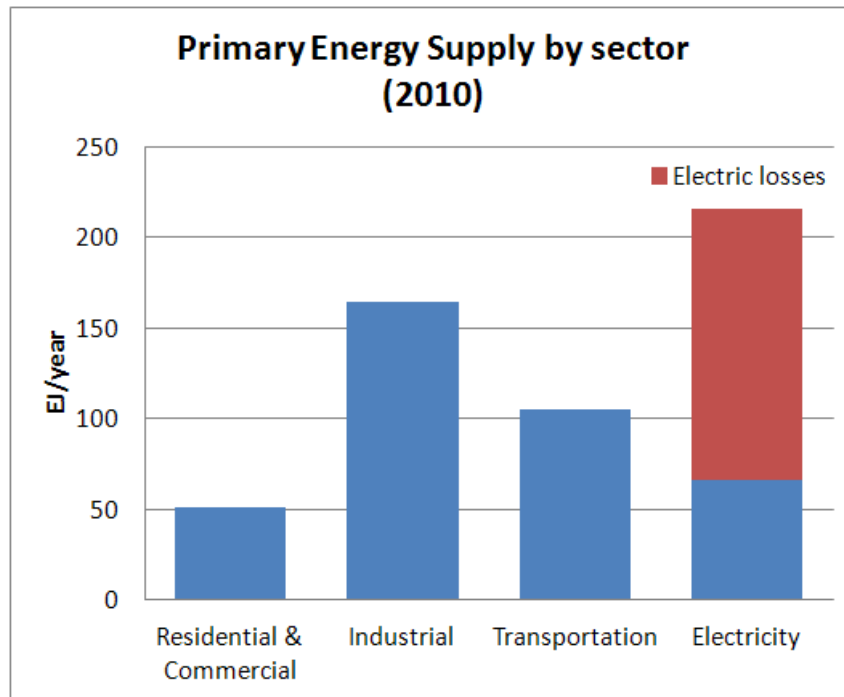
**Figure 14 (IEO, 2013): Primary Energy Supply by economic sector modeled in WoLim.**

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**.

<div align="center">i: economic sector</div>                    equation (7)
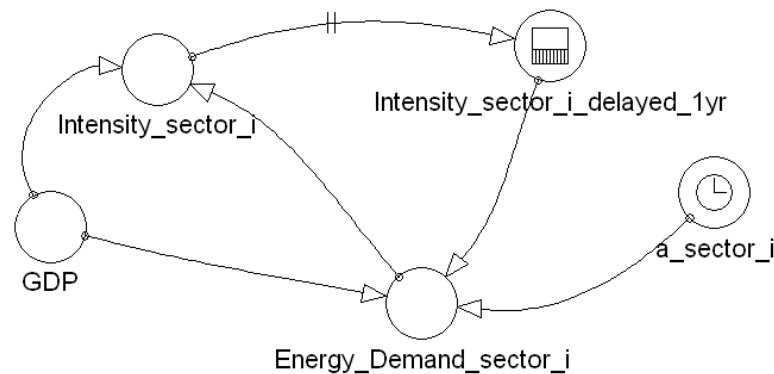


**Figure 15: Forrester diagram of the energy demand modelying by sector with the energy intensity method.**

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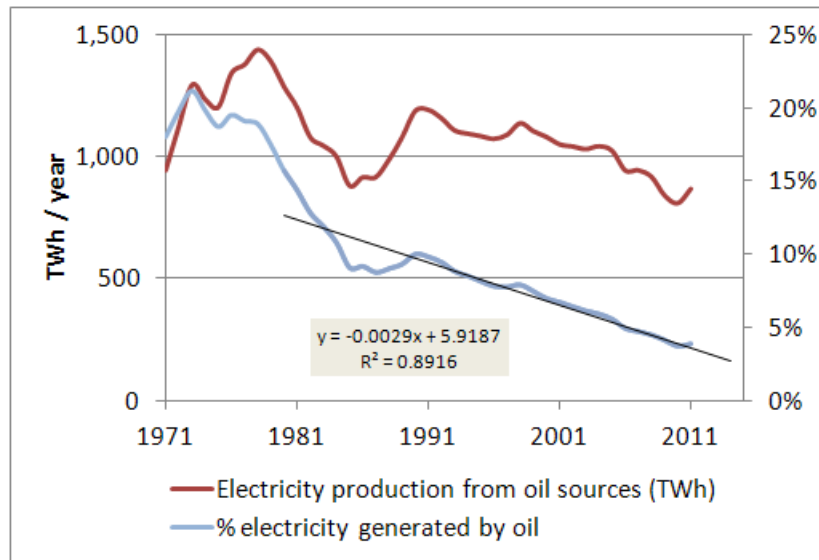
**Figure 16 (own analysis from (World Bank database, 2014)): Electricity production from oil sources (TWh) and as percentage of the total electricity production.**

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 18** 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.
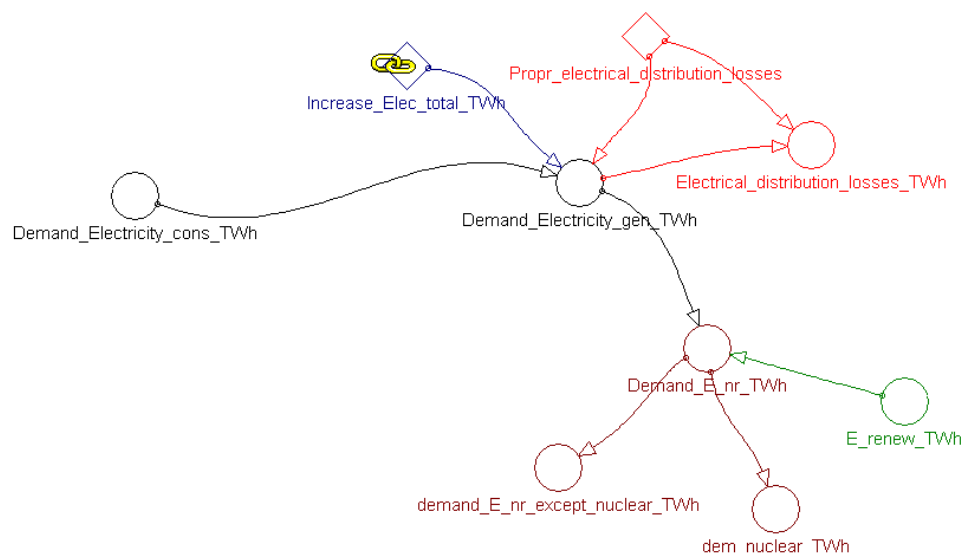


**Figure 17: Forrester diagram of the structure of the Electricity sector modelying in WoLiM.**

### 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.

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**

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

**Figure 19** 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 18**). Finally, the real energy intensity of the Transportation sector is calculated after the policies (**real_Transport_intensity**).



**Figure 18: Forrester diagram of the Transport sector modeling in the WoLiM model.**
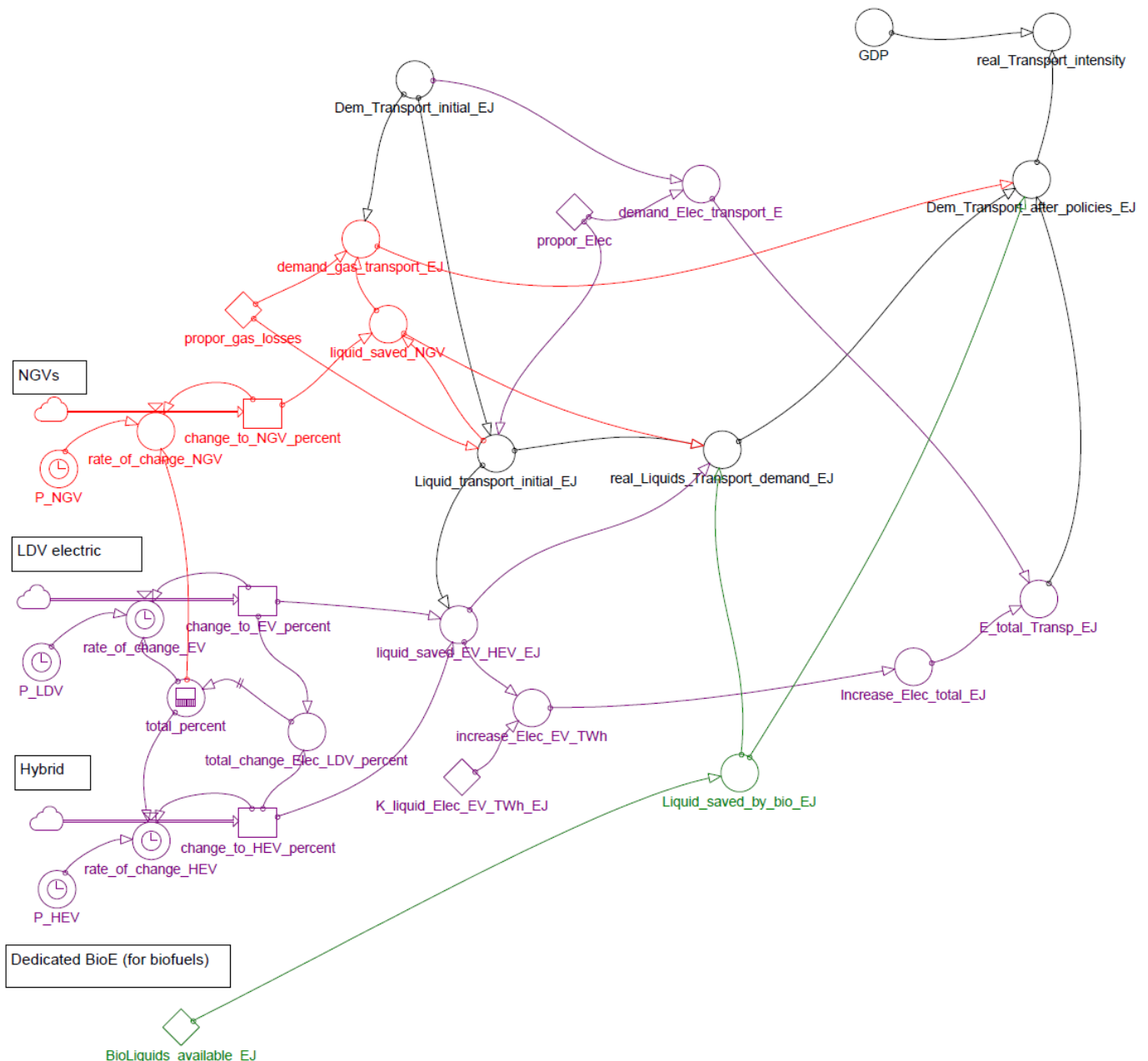
Transportation is a key sector, which has a strong dependency on oil and is essential for most industrial processes and services, and increasingly also for the food sector (Lassaletta et al., 2014). The lack of energy for transportation is expected to have an impact on all of the other sectors, especially in a strongly globalized economy.

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[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**.

### 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 20**) 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 20**), 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 20) 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 .**
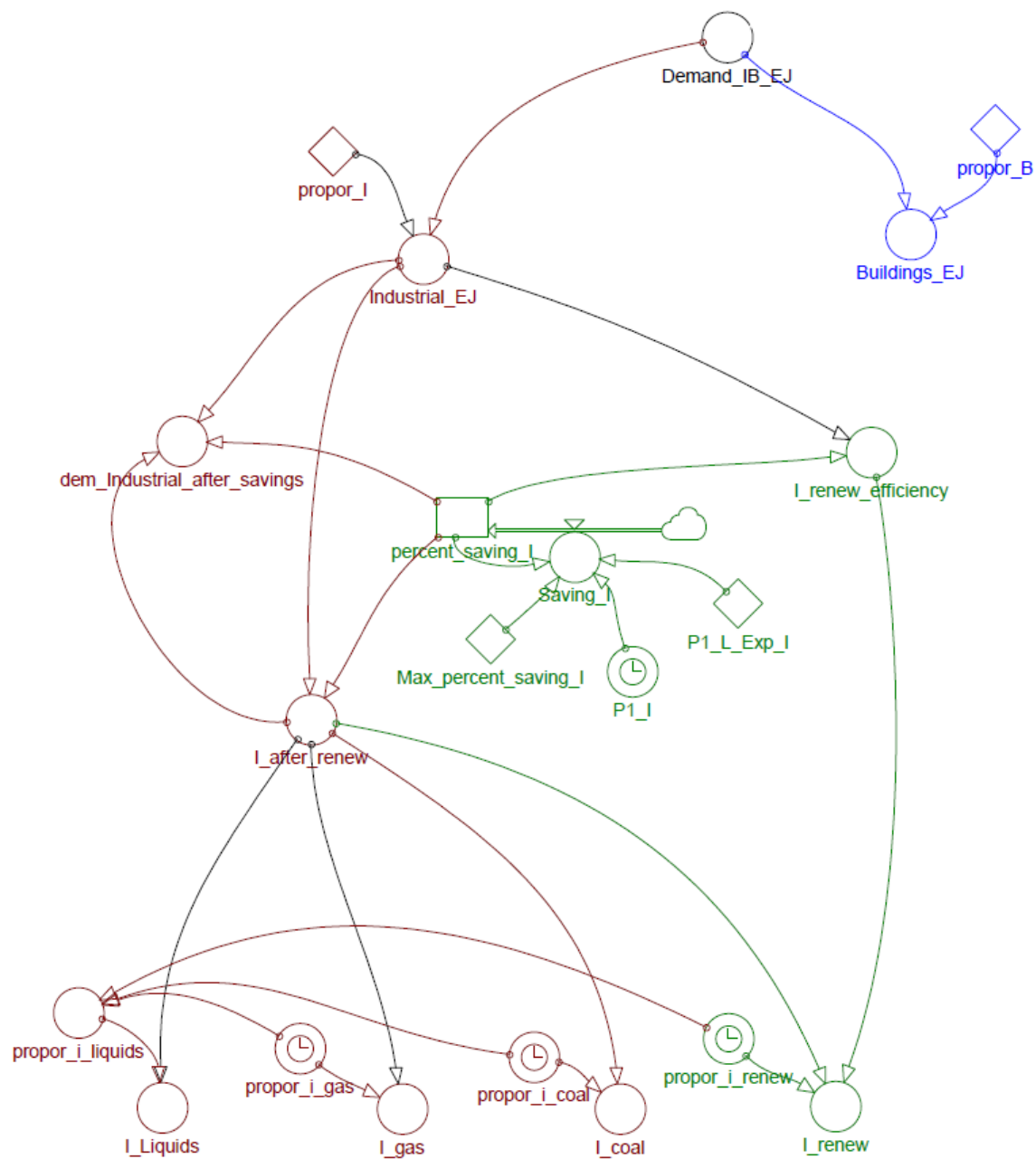
**Figure 19: Forrester diagram of the representation of the Industrial sector and the policies applied.**

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 9**) 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 | 0,65 |

| | | EJ * 0.8) | |
|---|---|---|---|
| | 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 11** 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 11 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

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[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.

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".

*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)**):

equation (8)

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

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)**):

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.

## 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.
- 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[15].



**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.**

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[15]    For a complete description of the model, please see (Capellán-Pérez et al., 2014). http://www.eis.uva.es/energiasostenible/?page_id=2056
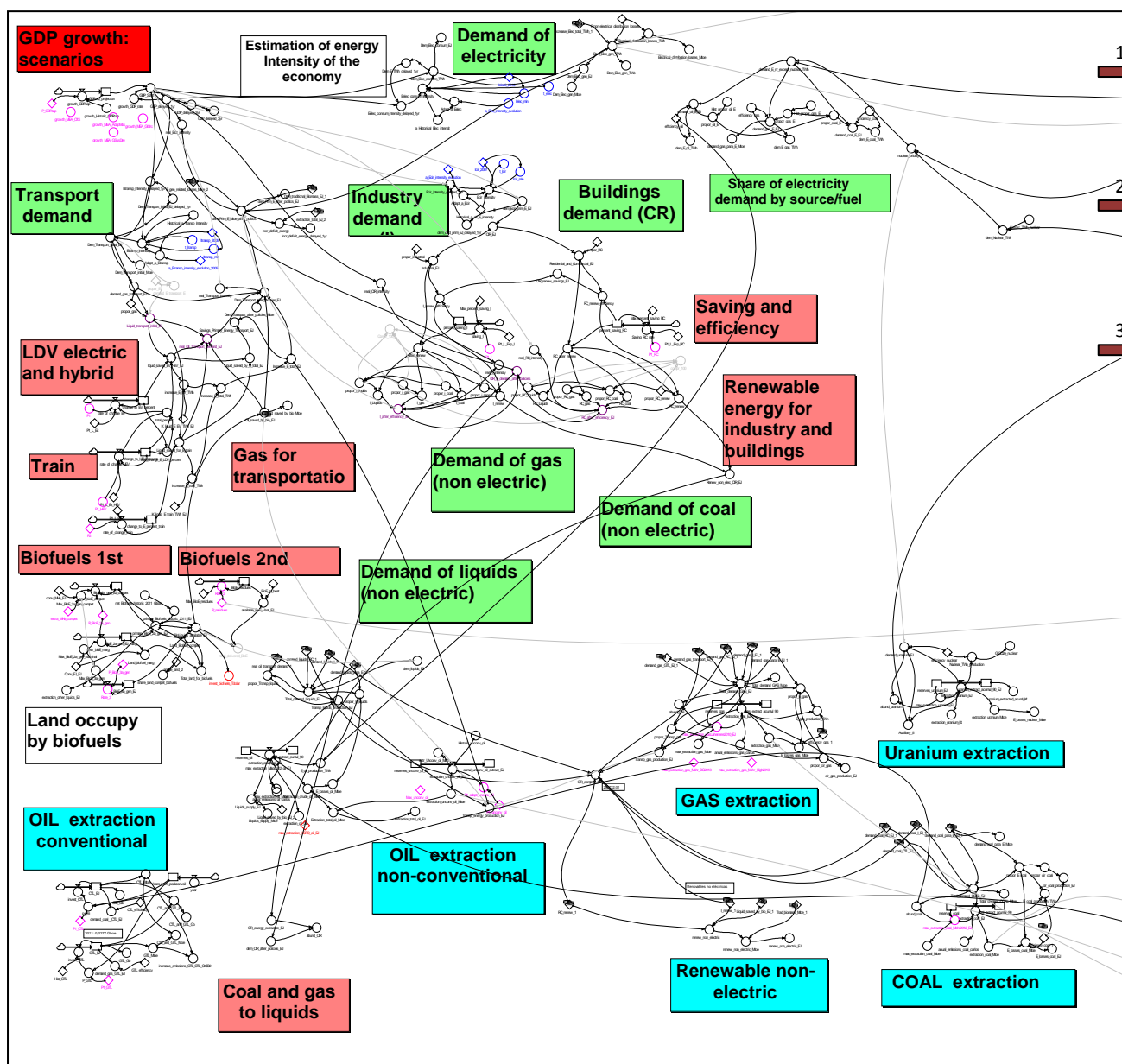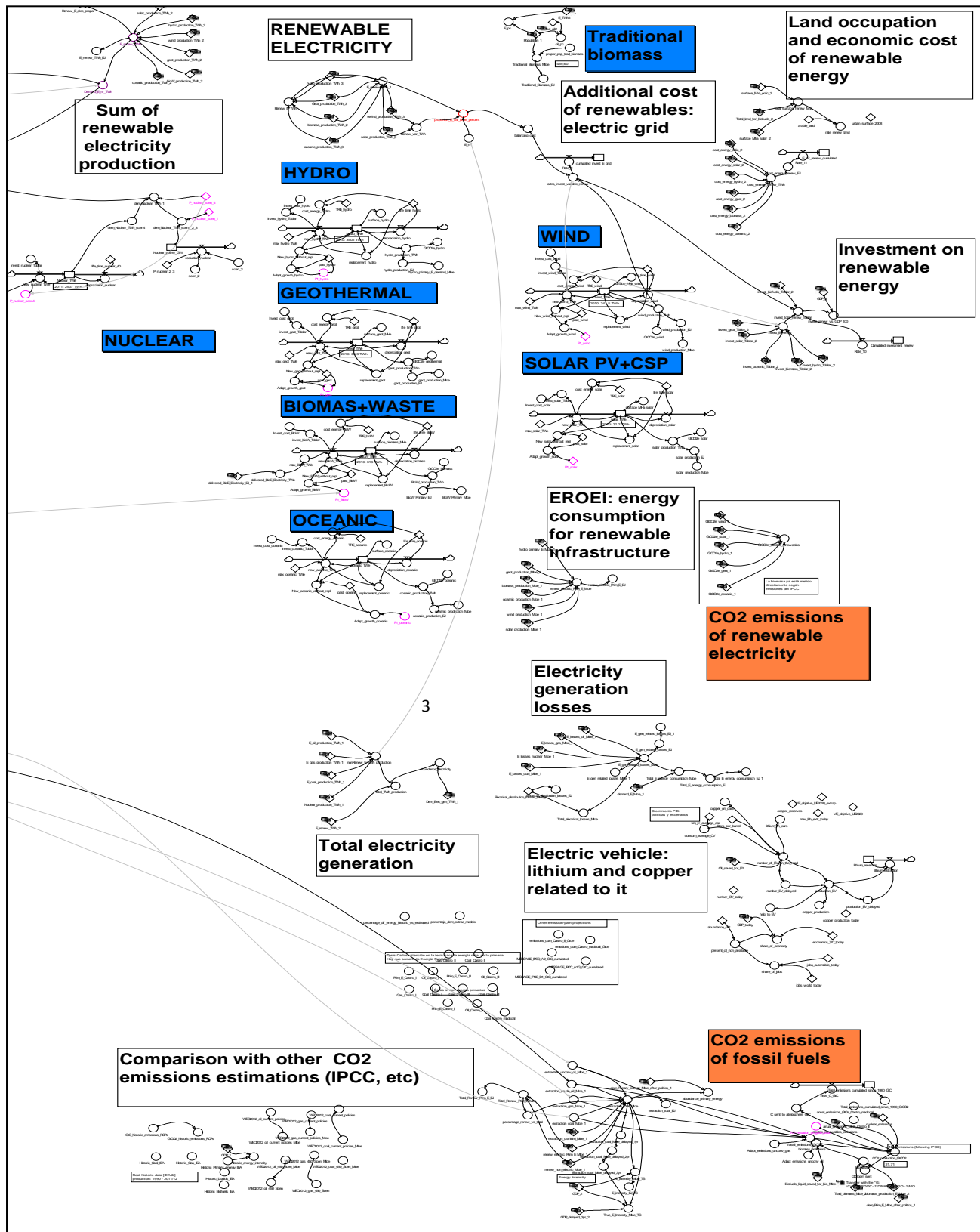
**Figure A2: Forrester diagram of WoLiM model (right side). Stocks are represented as squares, flows by the arrows related to stocks, variables are represented by circles and constant by rhombus. Most of the relationships between variables are represented by lines but some are hidden in order to simplify the graph.**

# Appendix B: 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,
3181.728,3175.592,3161.797,3141.211,3115.284,3085.905,3055.197,3025.335,2998.716,2977.043,2961.66,2953.52
4,2953.177,2960.781,2976.172,2998.939,3028.5,3064.183,3101.34,3138.559,3174.511,3208.264,3239.241,3267.14
1,3291.871,3313.465,3332.031,3347.679,3360.497,3370.532,3377.769,3382.148,3369.608,3346.488,3321.229,3294
.992,3268.097,3240.417,3211.631,3181.371,3149.303,3115.165,3078.779,3040.045,2998.944,2955.516,2909.855,2
862.099,2812.419,2761.007,2708.073,2653.84,2598.532,2542.372,2485.583,2428.504,2374.077,2323.461,2276.451
,2232.715,2191.899,2153.665,2117.705,2083.74,2051.52,2020.821,1991.447,1963.215,1935.965,1909.555,1883.85
3,1858.745,1834.127,1809.908,1786.007,1762.351,1738.881,1715.543,1692.293,1669.093,1645.913,1622.732,1599
.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
.188,2399.064,2438.956,2477.797,2515.499,2551.951,2587.027,2620.584,2652.477,2682.561,2710.696,2736.761,2
760.656,2782.311,2801.695,2818.816,2833.727,2846.525,2857.313,2865.651,2871.104,2873.467,2871.231,2859.31
5,2837.161,2804.26,2760.865,2707.913,2646.88,2579.6,2508.073,2434.288,2360.072,2286.979,2216.233,2148.709,
2084.941,2025.172,1969.391,1917.401,1868.877,1823.408,1779.848,1737.753,1696.691,1656.32,1616.383,1576.68
9,1537.111,1497.563,1458.001,1418.407,1378.781,1339.14,1299.507,1259.907,1215.026,1164.711,1113.385,1062.
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
.9811,187.0149,169.3649,152.9952,137.864,123.9239,111.1229,99.40564,88.71399,78.98808,70.16719,62.19049,5
4.99783,48.53019,42.73033,37.54315,32.91596,28.79883,25.14464,21.90927,19.05156,16.53339,14.31955,12.3776
9"Min:0;Max:1"])

aux     Coal_Castro_madcoal =
GRAPH(TIME,1985,1,[2058.92,2092.273,2125.719,2159.473,2193.76,2228.812,2264.86,2302.131,2340.839,2381.18
1,2423.341,2467.472,2513.705,2562.145,2612.867,2665.915,2721.307,2779.032,2839.057,2901.327,2965.741,3032
.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
.892,4683.411,4741.629,4802.568,4866.149,4932.233,4997.041,5059.895,5120.048,5176.957,5230.208,5279.471,5
324.457,5364.899,5400.523,5431.048,5456.18,5475.613,5489.039,5496.155,5485.533,5462.411,5433.003,5397.992
,5357.583,5311.761,5260.447,5203.567,5141.105,5073.113,4999.716,4921.113,4837.565,4749.388,4656.947,4560.
64,4460.897,4358.163,4252.895,4145.552,4036.593,3926.465,3815.603,3704.469,3595.324,3489.224,3386.159,328
6.012,3188.632,3093.869,3001.58,2911.633,2823.912,2738.311,2654.736,2573.108,2493.352,2415.405,2339.215,2
264.732,2191.917,2120.736,2051.16,1983.165,1916.732,1851.845,1788.493,1726.664,1666.349,1607.541,1550.236
"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+oce
anic_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+e
xtraction_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
.429,1806.879,1847.872,1888.313,1928.081,1967.036,2005.019,2041.852,2077.355,2111.337,2143.615,2174.009,2
202.365,2228.548,2252.451,2274.005,2293.183,2309.996,2324.497,2336.78,2346.972,2355.231,2360.563,2358.931
,2349.907,2333.019,2308.363,2276.557,2238.656,2196.021,2150.188,2102.723,2055.415,2009.484,1965.956,1925.
604,1888.937,1856.225,1827.532,1802.759,1781.692,1764.045,1748.045,1733.151,1718.828,1704.687,1690.467,16
76.02,1661.299,1646.324,1631.172,1615.956,1598.984,1581.356,1563.407,1545.421,1521.061,1491.535,1462.019,
1433.787,1407.576,1383.712,1362.231,1342.979,1325.688,1310.034,1295.677,1282.279,1269.524,1257.124,1244.8
21,1232.387,1219.624,1206.361,1192.453,1177.776,1162.232,1145.742,1128.249,1109.715,1090.121,1069.47,1047
.78,1025.089,1001.449,976.9292,951.6111,925.5873,898.9597,871.8369,844.332,816.5603,788.6367,760.6747,732.
7835,705.0673,677.6237,650.5427,623.906,597.7871,572.2503,547.3508,523.1355,499.6425,476.9019,454.9361,43
3.7605"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,[0.01639,0.01535,0.01523,0.01481,0.01486,0.01426,0.01411,0.01377,0.01337,0.01316,0.0126
7,0.01239,0.01223,0.01211,0.012,0.0119,0.01184,0.01182,0.01168,0.01152,0.01151"Min:0;Max:1"])

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

aux      growth_MEA_AdapMos =
GRAPH(TIME,2011,1,[0.016267,0.015683,0.015282,0.014738,0.015606,0.01567,0.016028,0.016217,0.016393,0.016
985,0.017123,0.017387,0.017496,0.017862,0.018465,0.018645,0.018808,0.018957,0.019334,0.019325,0.019427,0.
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
,0.018536,0.018308,0.018623,0.018388,0.018263,0.018088,0.017916,0.017699,0.017584,0.017422,0.01731,0.0171
52,0.017583,0.017367,0.017288,0.017079,0.016961,0.017503,0.017405,0.017307,0.017208,0.01711,0.017542,0.01
75,0.017455,0.017479,0.017427,0.017684,0.01765,0.017679,0.017669,0.017654"Min:0;Max:1"])

aux      growth_MEA_GlOrc =
GRAPH(TIME,2011,1,[0.030753,0.029979,0.029245,0.028414,0.0292,0.029262,0.029295,0.029422,0.029631,0.0302
52,0.030463,0.030416,0.030554,0.030653,0.031399,0.031483,0.031439,0.031547,0.031444,0.031738,0.031571,0.0
31547,0.031419,0.031421,0.031322,0.031133,0.030933,0.030853,0.030625,0.03082,0.030494,0.030286,0.030068,0
.029844,0.030249,0.029822,0.029407,0.029051,0.02889,0.029085,0.028752,0.028467,0.028099,0.027862,0.027226
,0.026775,0.026416,0.02603,0.025691,0.025188,0.024739,0.024374,0.024021,0.023711,0.023997,0.023646,0.0233
35,0.023063,0.02274,0.022565,0.022337,0.022112,0.021892,0.0217,0.021536,0.021348,0.021162,0.021001,0.0208
19,0.021329,0.021079,0.020879,0.020661,0.020467,0.019957,0.019861,0.019744,0.019665,0.019563,0.019406,0.0
19429,0.019427,0.019417,0.019434,0.018882,0.018857,0.018842,0.018821,0.018811"Min:0;Max:1"])

aux      growth_MEA_GSusDev =
GRAPH(TIME,2011,1,[0.022894,0.022229,0.021746,0.020991,0.021416,0.021806,0.021751,0.022091,0.022269,0.02
3065,0.023171,0.023381,0.023445,0.023726,0.024318,0.024409,0.02448,0.024745,0.024769,0.024778,0.024869,0.
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
,0.02275,0.022435,0.022577,0.022371,0.022095,0.021932,0.021735,0.02144,0.021252,0.021066,0.020914,0.02073
1,0.021003,0.020778,0.020586,0.020398,0.02024,0.020628,0.020531,0.020405,0.02033,0.020251,0.020513,0.0205
1,0.020523,0.020504,0.0205,0.020711,0.020704,0.020689,0.020688,0.020658"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,
0.0096,0.0097,0.0098,0.0099,0.0106,0.0108,0.0107,0.0109,0.0107,0.0114,0.0112,0.0114,0.0114,0.0114,0.0117,0.01
18,0.0118,0.0119,0.012,0.0127,0.0128,0.0129,0.0129,0.0129,0.0135,0.0136,0.0135,0.0137,0.0136,0.0142,0.0142,0.0
142,0.0141,0.0142,0.0143,0.0143,0.0144,0.0144,0.0144,0.015,0.0151,0.0151,0.0151,0.0152"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,[1908.807,1996.14,2015.603,2081.627,2125.16,2210.045,2291.532,2271.307,2316.009,2393.1 32,2449.889,2516.674,2545.302,2517.757,2617.323,2639.244,2659.825,2597.7,2602.65,2568.41,2620.22,2507.24" Min:0;Max:3000"])

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

aux      Historic_unconv_oil = GRAPH(TIME,1990,1,[1.955933,2.04395,2.135928,2.232044,2.332486,2.437448,2.547133,2.661754,2.781533,2.906 702,3.037504,3.174192,3.31703,3.466296,3.62228,3.785282,3.95562,4.133623,4.319636,4.51402,4.717151"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,[0.9990634,1.004318,0.9948779,0.9978247,0.9942701,1.001174,0.9861589,0.9909408,1.0045 54,0.9910916,0.9629158,1.003049,1.006062,1.007066,0.9909275,0.9919123,1,1"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"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
.413,3751.42,3766.075,3775.242,3778.863,3776.956,3769.611,3756.989,3739.309,3716.84,3688.035,3646.763,359
2.805,3525.96,3446.962,3357.361,3259.305,3155.317,3048.036,2940.002,2833.899,2731.449,2633.989,2542.411,2
457.184,2378.413,2305.916,2239.297,2178.03,2121.511,2067.406,2015.014,1963.69,1913.006,1862.722,1812.749,
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,
931.6077,926.3064,923.0253,921.7311,922.3853,924.9388,929.328,935.4695,943.2591,952.5689,963.2484,975.122
7,987.9961,1001.654,1015.864,1030.382,1044.956,1059.326,1073.235,1086.426,1098.651,1109.674,1119.273,1127

.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.
467,3591.829,3658.603,3723.549,3786.388,3846.792,3904.397,3958.811,4009.623,4056.415,4098.78,4136.269,416
9.568,4198.244,4222.148,4241.187,4255.331,4264.623,4269.172,4269.148,4264.781,4256.344,4242.113,4215.119,
4174.811,4120.764,4053.659,3975.156,3887.669,3794.084,3697.453,3600.705,3506.777,3417.656,3334.639,3258.4
36,3189.167,3126.444,3069.497,3017.289,2968.647,2922.373,2873.737,2821.484,2764.724,2703.172,2637.043,256
6.929,2493.688,2418.331,2341.936,2265.579,2190.285,2116.993,2046.543,1979.652,1909.205,1839.499,1776.009,
1719.364,1669.547,1626.187,1588.743,1556.592,1529.084,1505.569,1485.408,1467.992,1452.74,1439.116,1426.62
8,1414.832,1403.339,1391.811,1379.965,1367.569,1354.44,1340.44,1325.472,1309.436,1293.544,1278.69,1264.85
2,1251.89,1239.628,1227.886,1216.495,1205.302,1194.168,1182.97,1171.597,1159.952,1147.952,1135.523,1122.6
04,1109.144,1095.102,1080.449,1065.164,1049.239,1032.671,1015.47,997.6508,979.2383,960.2639,940.7653,920.
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
.413,3751.42,3766.075,3775.242,3778.863,3776.957,3769.559,3756.017,3735.729,3708.446,3672.294,3621.032,35
54.529,3472.852,3377.149,3269.456,3152.433,3029.071,2902.393,2775.218,2649.975,2528.602,2412.501,2302.569
,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,
361.2165,335.808,311.6429,288.6826,266.8945,246.2505,226.7259,208.2974,190.9427,174.6384,159.3601,145.081
8,131.775,119.4089,107.9503,97.36357,87.61117,78.65368,70.45028,62.95921,56.13819,49.94475,44.33675,39.27
273,34.71215,30.61577,26.94585,23.66634,20.74301,18.14354,15.83763,13.79698,11.99527,10.40818,9.013323,7.
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,

2359.843,2301.896,2247.696,2197.163,2150.199,2106.687,2066.499,2029.493,1995.519,1964.42,1936.032,1910.19
2,1886.735,1865.496,1846.316,1829.037,1813.511,1799.592,1787.143,1776.033,1766.143,1757.355,1749.564,1742
.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
.554,9539.376,9728.585,9921.493,10118.22,10318.67,10522.55,10729.35,10938.39,11148.8,11359.55,11569.52,11
786.26,11999.63,12211.42,12420.76,12626.87,12829.17,13027.26,13220.99,13410.47,13596.08,13773.95,13924.74
,14047.57,14141.5,14208.26,14251.81,14277.76,14292.74,14303.69,14317.33,14343.2,14382.91,14441.39,14521.6
3,14625.64,14754.65,14909.23,15089.46,15295.09,15525.66,15768.71,16021.36,16282.45,16551.25,16827.53,1711
1.32,17402.73,17701.79,18008.38,18322.16,18642.56,18968.79,19299.77,19634.24,19970.72,20218.39,20503.91,2
0792.28,21081.97,21370.64,21655.54,21933.86,22202.84,22459.86,22702.48,22928.43,23135.65,23322.28,23486.6
7,23627.39,23743.2,23833.11,23896.32,23932.27,23940.62,23921.26,23874.3,23810.4,23774.22,23752.98,23746.1,
23752.7,23771.78,23802.33,23843.32,23893.74,23952.59,24018.87,24091.56,24169.68,24252.21,24338.13,24426.4
2,24516.07,24606.07,24695.39,24783.03,24868,24949.32,25026.04,25097.24,25162.02,25219.53,25268.95,25309.5
3"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 sector 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_polit
ics_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,[0,29.97832,46.74028,59.49534,71.36029,84.93571,96.09971,107.4647,118.4603,127.5374,137.0181,145.8883,152.0052,156.2876,162.4698,166.6593,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044,171.044"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