

Scenarios of energy and environment futures impacting the selection and diffusion of ULCOS technologies

Paper presented at the 2nd ULCOS Seminar 2005 – Aveiro 21-22nd september, Portugal

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Abstract

This paper aims at explaining the use of the energy and climate scenarios which will be studied in the ULCOS project and the methodology used to define them. Figures displayed on the energy reference and costs of technologies are preliminary results.

Keywords:

Climate Change, energy futures, economic modelling

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1 INTRODUCTION

The world energy system is now subject to a double constraint : “upstream” with the building up of tensions on the oil market and the threat of a peak oil, “downstream” with GHG emission constraint. Indeed, momentum is growing globally such that action to reduce greenhouse gases (GhG) emissions may be required. However, preliminary simulations on the costs of ULCOS routes show a strong sensitivity to energy prices and to the CO₂ content of electricity.

Price of final energies will depend on the complex and dynamic interactions between resource constraints (for oil and gas), climate policies and energy policies ...

However, not all the combinations of fundamentals are possible and applied models may help in identifying consistent sets for technology (and investment) planning.

This paper aims at explaining the use of the energy and climate scenarios which will be studied in the ULCOS project and the methodology used to define them .

First, we present why energy prices and carbon constraints will impact the dynamics of existing and upcoming ULCOS technologies.

Secondly, we focus on the use of scenarios to simulate different energy and climate futures and we detail the POLES model ((Prospective Outlook for Long-term Energy Systems) which is used.

Thirdly, we detail the key sets of hypotheses that have been used for the different scenarios in terms of world population and economic growth, oil and gas resources and future energy technology costs and performances.

Both limits of the existing steel technologies / socio-technical system and the energy & climate change challenge would induce changes in the production, distribution and consumption patterns of steel and other materials. Formulating energy scenarios is a means of generating common knowledge. Models can exhibit future behaviour of complex systems simply by isolating important system aspects and key feedbacks from unessential detail.

2 KEY ISSUES IN THE DIFFUSION OF STEELMAKING AND ULCOS TECHNOLOGIES INDUCED BY RISING ENERGY PRICES

The dynamics in the world energy system and the anticipated increase in the price of carbon will induce changes in the relative prices of different fuels as well the order of preference of different steelmaking technologies. This section provides an overview on how this evolution will impact the dynamics of steel technologies and particularly the ULCOS breakthrough technologies and how it is modelled.

Indeed, Clarke and Weyant [1] identify three aspects of uncertainty that need to be considered when modelling “induced technological change” :

- Uncertainty on the performance potential of each individual technique
- Heterogeneity and discontinuity in the technology development
- Impacts of major exogenous inventions or from spillovers.

The issue of induced technological change has been quite extensively addressed in the energy sector, but less so in the energy intensive manufacturing industries and for breakthrough technologies.

The following sections show the sensitivity of emerging ULCOS technologies to different “environment of selection”, in particular energy and carbon prices and the need for appropriate modelling. Of course, other factors will play a role. Conditions of technology development and discontinuity in the steel industry will be detailed in a extensive way in future papers.

2.1 Increasing operating cost and induced technical change

In the near and long term future, the different GhG emitting sectors will have to face an increasing “carbon constraint” and limit their emissions. Numerous exercises have tried to capture the effect of the introduction of a carbon tax or emissions quotas, specially because of competitiveness issues [, , , ,]

Even with little constraints resulting from the first application of the EU Emission Quota Trading System and the Kyoto Protocol (-8% for EU in 2012 compared to emissions of 1990), the climate constraint is said to imply a significant increase in the operating costs. Simulations performed at IEA, with hypotheses corresponding to average EU conditions, are reproduced in Table 1.

Table 1 : Increase in total costs per tonne of finished products assuming full opportunity cost,

Carbon price E/ t CO ₂	Electricity	Steel (BOF)	Steel (EAF)	Cement	News-print	Aluminium
5	5%	0.2%	0.4%	0.7%	0.5%	1.2%
10	11%	0.5%	.08%	1.5%	1.1%	2.4%
15	16%	0.7%	1.3%	2.2%	1.6%	3.6%
30	32%	1.5%	2.5%	4.5%	3.3%	7.2%

Source : IEA, 2004 [2]

Considering the ULCOS technologies, the operating costs will of course vary with the price of energy and carbon. The merit order of each technology will vary.

2.2 Merit order, lock-in effects and the adoption of ULCOS technologies

Preliminary simulations show a strong sensitivity to energy prices and to the CO₂ content of electricity, at least in Europe. The conditions for new technologies to enter the system have to be studied in great detail. In the next decades, inter-technology competition will take place in a much more complex set of economic fundamentals than in past decades, with profoundly altered competitive advantages or merit-order.

However, pioneering work by David [3] and Arthur [4] already highlighted situations of “lock-in” of an industry in sub-optimal technologies because of increasing returns to adoption and path-dependency.

Whereas most recent work on technological lock-in is applied to carbon based energy systems [5,6,7], studying emissions reductions potential in the material industry is of great promise [8]. Until now, there has been few research and modelling exercises dedicated to this subject and to

the introduction of new radical technologies for the long term.

Moreover, it can also be argued that modern, complex technologies in the steel industry may also display increasing returns to adoption in that the more they are adopted, the more experience is gained with them, and the more they are improved. In the steel industry, Luiten [9] provided some work on the lock-out of strip casting even if the huge capital cost advantages of strip casting technology were already noticed back in the 19th century.

For each ULCOS technologies, qualitative discussion will enable to estimate the possibilities of lock-in, particularly dangerous in case the fuel mix they rely on, is undergoing major change in prices or availability.

But supposing lock-ins can be superseded the following key question is that of the rate of diffusion of new technologies.

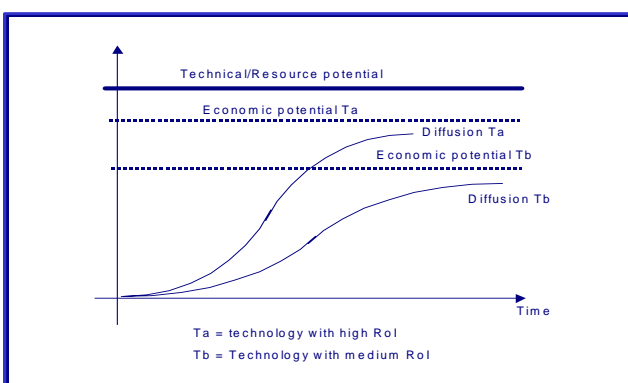
2.3 Diffusion of technologies

Indeed, since the first industrial revolution² steelmaking technologies have experienced different rates of diffusion depending on many factors. Some processes, such as the Bessemer process, had a rapid diffusion rate but were then fully replaced. Other processes, such as the blast furnace, electric arc furnace, and hot strip mill, have evolved continuously over the decades and are thus likely to remain part of steelmaking in the future.

The conventional approach to modelling the diffusion of technology takes into account the technical and the economic potential of the technologies.

Typically, the fraction of potential users that has adopted a new technology follows a sigmoid or "S-shaped" path over time, rising only slowly at first, then entering a period of very rapid growth, followed by a slowdown in growth as the technology reaches maturity and most potential adopters have switched [10].

Figure 1 : Framework for modelling diffusion of new technologies in POLES.



A broader range of factors than the sole energy / carbon prices are likely to affect technology diffusion, amongst them the characterisation of potential adopters. Indeed, adoption and speed of diffusion is related to firm size, human capital, regulatory costs of the old technology, factor prices, complementary infrastructure, industry growth and R&D expenditures or capital vintage.

A dedicated module on steel industry (ISIM) has been developed at IPTS [11] to describe those issues. It is coupled to the POLES model which is used to simulate different energy futures under different scenarios.

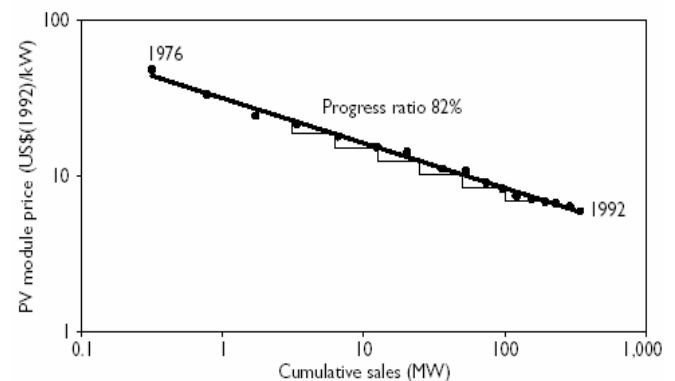
2.4 Learning curves

Learning curves are now of common use in many bottom-up energy models.

This notion enables to introduce endogenous technical change by implementing so-called learning-by-doing rates for specific energy technologies. *Learning curves* rely on the concept of learning-by-doing (LbD) and learning-by-using (LbU³). The costs of production and/or abatement decrease due to experience, i.e. knowledge is accumulated through production and/or abatement itself.

Historic development of investment cost for different energy technologies over the cumulative installed capacity have been studied extensively as shown in figure 2.

Figure 2. Experience Curve for Photovoltaic Modules, 1976-1992



Source : IEA, 2000 [12] (Double-logarithmic representation of an experience curve)

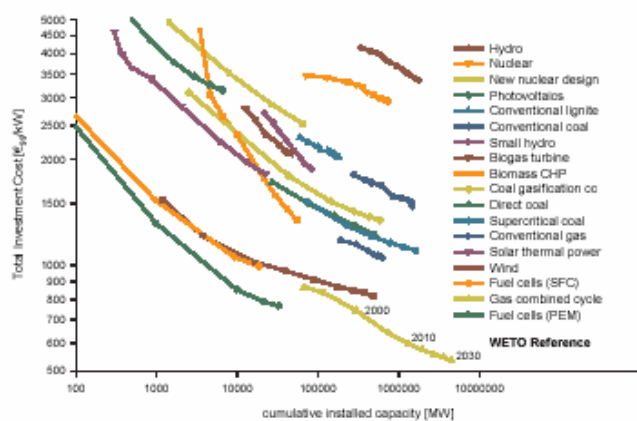
Forecasting technology development is a highly speculative activity, especially for a long-term time horizon. However, considerable efforts have been recently made to improve the modelling of technology development in energy models. Recent developments in different EU DG Research projects (particularly SAPIENT and SAPIENTIA) have been concentrated on the incorporation of the so-called two-factor learning curves, allowing the taking into account of "learning by searching" and the endogenisation of R&D expenditures. Two factor learning curves quantify the correlation between R&D spending in energy technologies and the induced technological progress.

A crucial assumption about both R&D and learning curves is that they respond to changes in relative prices. Hence, changes in the direction and speed of technological change can be induced by pervasive changes in relative prices. Experience curves demonstrate that investment in the deployment of emerging technologies could drive prices down so as to provide new competitive energy system

Figure 3. Learning curves for power generation up to 2030.

² See for example : G. Giauque, the history of carbon steel, *The book of steel* pp5 – 10, Lavoisier Tec&doc, Paris 1995

³ Rosenberg (1982) , see also Atkinson and Stiglitz (1969)



Source : POLES WETO 2030

In the ULCOS project, learning curves will be established for ULCOS technologies up to the time horizon considered (2030-2050). Hence the total costs of different technologies will vary along the simulation period and modify the order of preference of the technologies, and so their adoption and diffusion.

3 ENERGY AND CLIMATE CHALLENGE : THE USE OF SCENARIOS

3.1 Quantitative and qualitative scenario analysis

The word « scenario » has different meanings in the different communities that use it and is an evolving concept. The term has been applied to diverse efforts ranging from literary descriptions to model-based projections, from visionary thinking to minor adjustments to “business-as-usual” projections.

Scenario development is a systematic way of thinking. The term scenario, borrowed from the theatre, describes an effort to tell a consistent, transparent story about the future. Integrated scenarios may be thought of as coherent and plausible stories, told in words and numbers, about the possible co-evolutionary pathways of combined human and environmental systems.

They generally include a definition of problem boundaries, a characterization of current conditions and processes driving change, an identification of critical uncertainties and assumptions on how they are resolved, and images of the possible future, sometimes called “futuribles”.

The US Board on Sustainable Development (NAS, 1999) listed four criteria for evaluating scientific strategies for exploring sustainable futures in policy contexts: scientific credibility, political legitimacy, practical utility and effectiveness.

After the Brundtland Report (WCED, 1987) and the 1992 Rio World Conference on Environment and Development, a second “wave” of global scenarios was launched in the context of the sustainability challenge. The scenarios of WBCSD in 1997 still marks the central initiation of the debate on sustainability [13]. Then, huge work was performed in the *quantitative* (modelling) and *qualitative* (narrative) traditions of scenario analysis.

One of the main contribution to explore the problem of transition to sustainability in a global and long-term perspective is the project of the Global Scenario Group at the Stockholm Environment Institute. An important concept in constructing scenarios is the distinction between slow

and fast dynamics operating within the socio-ecological system [14, 15].

Since those seminal contributions, prospective or forecasting techniques have been applied in many sectors, especially to explore energy or climate futures. Royal Dutch/Shell’s famous global strategy group was one of the pioneers, some three decades ago, in developing application of scenarios to corporate strategy.

Formulating energy scenarios is a means of generating common knowledge in other words, a form of inquiry. Models can exhibit future behaviour of complex systems by reducing inconsistencies and arbitrary statements and by isolating important system aspects from unessential detail.

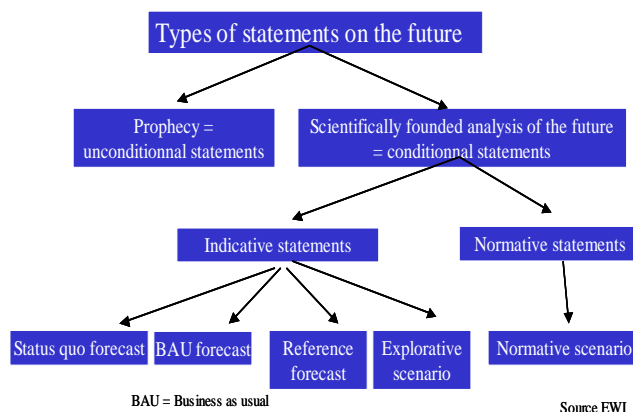
3.2 The use of scenarios for energy futures

Exploring the future with energy economics models is best done in scenarios. Best known exercise include the IPCC-SRES series of greenhouse gas emissions (GhG) scenarios [16], exercises performed at IEA [17] and the WETO (World Energy, technology and climate policy Outlook) from DG Research of the European Commission [18] or national exercise [19,20,15] like the “four energy futures” study by the Central Planning Bureau in the Netherlands

Reference scenario serves as a point of reference for policy and target scenarios and serve to identify the need for action in the future.

This practice establishes a baseline projection, against which experiments can be run by testing the changes in energy use or prices, or the reductions in carbon emissions, resulting from changes in the assumptions. Most of the time, it is derived from a “Business-as-usual” case, which more or less, continues past trends.

Figure 4 : Scenarios provide different types of statements on the future



Source : EWI/Prognos Energy 2030 Study for the BMWA [21]

Any reduction goal compatible with climate stabilisation will have considerable effects on economic activities, markets and behaviours. Considering the important challenge of reduction of GHG emissions by a “factor4”, it is still hard to describe how economies could evolve towards a much less carbon-intensive path. The scenarios which are studied in the ULCOS project do clearly belong to the categories of “reference and explorative scenario”

The key questions are : what drives the model ? What are the functions that create change, and what are their variables ? Work performed in ULCOS relies on the POLES (Prospective Outlook for Long-term Energy

Systems) model, which transparent structure will enable to discuss the opinions, hypothesis and intermediate results.

3.3 The POLES Model

The simulation process in the POLES model basically reflects the dynamics and adjustments of world demand and supply.

The POLES Model

The POLES (Prospective Outlook for Long-term Energy Systems) model is a partial equilibrium model of the world energy system, developed since 1990 and applied to policy assessment since 1997, under the co-ordination of Lepii-EPE (ex-IEPE) and in particular with IPTS [22]. This model is currently used by the European Commission for energy and climate policy simulation. POLES simulates in a recursive year-by-year process the supply and demand of the major energy carriers within the period 2000-2030, and endogenously computes their prices. The main advantages of the model are its comprehensive and detailed structure (regional and sectoral desegregation), the fact that it provides elements for the endogenisation of technological change and its capabilities for the analysis of technological progress in the context of CO₂ abatement policies.

In complement to the main model, the POLES architecture also relies on numerous dedicated modelling tools or database:

- **Endow** organises all relevant information on national emission targets and sectoral National Allocation Plans, with particular detail for those countries under the European Quota Trading System (EQTS)
- **ASPEN** simulates the EQTS, with sectoral detail and different market configurations:
- **Transmat** simulates long term material demand and inter-material substitution
- **TechPOL** provides reliable data on costs and performance for the POLES model energy technologies through a consolidated interactive process

The TechPOL database

POLES considers 12 conventional and 12 alternative technologies for power generation as well as technologies for hydrogen production. The change in relative prices of energy sources changes the production costs of the technologies. Lepii-EPE developed a technology database for the energy programme of CNRS. Technology specific costs of production are available on request.

This modelling system allow to provide consistent images of the world with transparent hypotheses and the possibility to test alternative views on resources, technologies and policies

3.4 Emissions profile and GhG reductions

Climate change is related to a variety of factors associated with human activity and the biosphere. When tackling these questions, climate models and economics models are generally coupled for long-term strategies. GhG Emissions are related to a set of assumptions and scenarios on population growth, economic growth, etc.

Following agreements at the UN Convention on Climate Change, most recent scientific work indicate that the policy goal should be to limit average global temperature increases to no more than 2°C of pre-industrial levels, which would already have serious impact. Therefore, meeting this climate objective will require a peak in world emissions within a few decades and a strong decrease to stabilise the concentration in atmosphere.

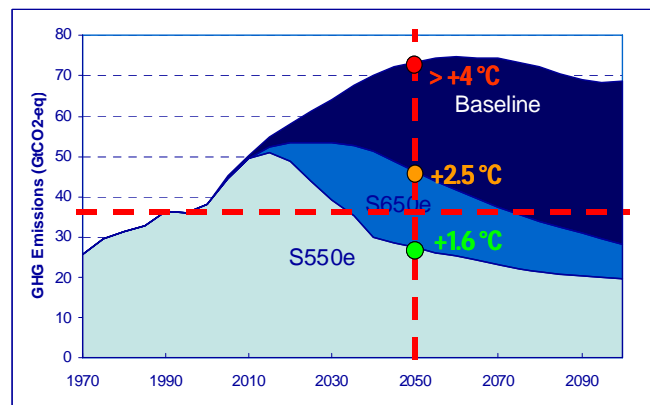
Most scientific work available has thus far assumed that reaching the 2°C target would translate into a long-term greenhouse gas (GhG) concentration level lower than 550 ppm CO₂ equivalent [23] (which means 450 ppmv CO₂ only) in the atmosphere.

Such level of concentration is still subject to uncertainty and new scientific knowledge may become available in the future, specially on the climate sensitivity factor [24]. The German Advisory Council (WBGU) has recommended the stabilisation of CO₂ concentration in the atmosphere below 450 ppmv [25].

Considering the hypothesis in the Common POLES-IMAGE (CPI) work, the resulting global reduction challenge is shown in the figure 5.

The baseline describes the development in the main driving forces (population and economic growth) and environmental pressures (energy, industrial and land-use emissions) for the 1995-2100 period with « Technical Change and Policy as usual ». It serves in particular as a benchmark for the assessment of alternative policy schemes.

Figure 5 : World emissions profile for different CO₂e concentrations in atmosphere.



Source : IMAGE2.2 [26]

A recent study "GhG Reductions Pathways" [26] looked at options for a future climate change regime. A concentration level of 550ppm CO₂e (CO₂ equivalent, for the 6 GHG in the Kyoto Protocol) would translate into a global reduction of GHG emissions of 15 – 20 % by the year 2050 compared to 1990 emission levels or by 50 – 60 % compared to a 2050 "business as usual" scenario. The challenge would be particularly important for industrialised countries, as reduction would be important to enable emissions of developing countries to increase.

Preliminary research indicate that 50-75% emissions reduction would lead to much higher CO₂ prices than those in table 1, with maybe a difference of one order of magnitude. But these assessment should encompass radical technological innovations and materials are a central factor for radical changes in industrial products. Therefore, cutting the adjustment costs is a key challenge for future competitiveness and growth.

4 MAIN ASSUMPTIONS IN THE DIFFERENT SCENARIOS AND PRELIMINARY RESULTS

The key sets of hypotheses that have been used for the Reference projection refer to world population and economic growth, oil and gas resources and future energy technology costs and performances. In all cases the projected trends correspond to an extrapolation of existing structural changes, which in no way implies, as illustrated below, an homothetic development of the world system.

In this section, we present the main macro economic assumptions that are used and the main hypothesis in the different scenarios.

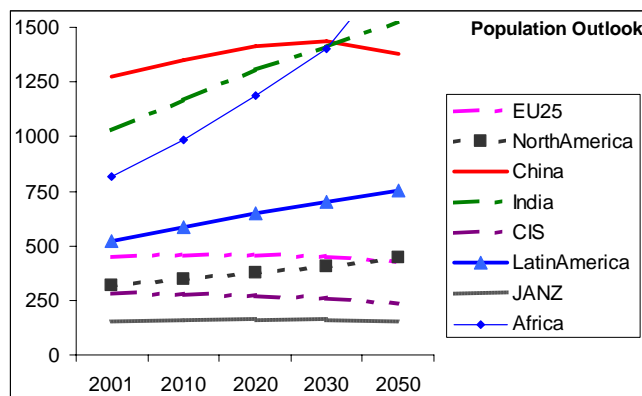
The simulations with different climate constraints will enable to assess the influence of regulatory or market pressure, as identified in theoretical and empirical work by Jaffe & Stavins [27,28] or Blackman & Bannister [29], on the ULCOS technologies introduction and diffusion.

4.1 Macro-economic assumptions

A variety of factors related to human activity interact to produce global environmental change: the interactions between population change, technological change, and socio-economic/cultural organization structure the patterns of production, consumption, and impacts throughout the world.

The population growth assumptions used in the Reference Case are derived from the United Nations demographic forecasts.

Figure 6 : Population growth, main regions

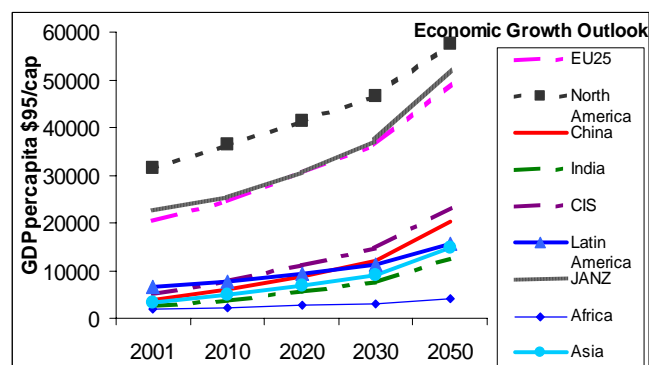


Source: POLES model exogenous hypotheses, May 04 2005

The world economic growth outlook results from the joint analysis of LEPII-EPE and CEPII⁴.

World economic growth is expected to continue on a sustained 3 % p.a. until 2030, then it slows down to an average 2 % p.a. between 2030 and 2050. This is mostly due to the combined slowdown in population growth and in per capita GDP by the end of the period under review.

Figure 7 : GDP, main regions



Source: POLES model exogenous hypotheses, May 04 2005

4.2 Oil and gas resource

the hypotheses on oil and gas resources are of particular importance as the situation on the oil markets, as well as a series of recent studies⁵ indicate a current and possibly long-lasting tense supply-and-demand balance.

What is to be discussed in any long term energy outlook has to deal with the issue of a possible "peak oil" – and probably later a "peak gas" – that many geologists identify as impending for a near future. This is obviously a major issue as it will clearly structure the future of the energy system and the development of the competing energy technologies in the next decades.

The US Geological Survey 1999 Study is the source of information used in the Reference scenario for oil and gas Ultimate Recoverable Resources, because it provides a set of estimates and attached probabilities that are consistent on a world and on a region-by-region basis. More precisely, the Reference Case is based on the "50% probability" estimate of the USGS study.

The first simulations produced with these hypotheses and the POLES-2050 model indeed described a phenomenon of "peak oil" occurring between 2030 and 2040 and accompanied with significant price increases, even from today's quite high levels. This indicates that the logic of the POLES-Oil and Gas Module is indeed adapted to long term studies that have to take into account relative resource scarcities and their impacts on international energy price.

Further on, more attention has been devoted to the final definition of the oil and gas resources, in particular in the project's framework and with a cooperation with the Institut Français du Pétrole (IFP). IFP indeed reviewed all the hypotheses used in the POLES model on Ultimate Recoverable Resources, discoveries, reserves and cumulative production and, finally recovery rates. This allowed to improve significantly the quality of the information used in the model and introduced significant – if not major – changes in the results

4.3 Technology description

Technological developments regarding energy technology costs and performances are derived from analyses elaborated in the framework of collaborative projects within

⁴ Centre d'Etudes Prospectives et d'Informations Internationales (Paris)

⁵ in particular Oil and Gas Journal, Feb. 21 and Mar. 7, 2005, and IMF, April 2005 World Economic Outlook: <http://www.imf.org/external/pubs/ft/weo/2005/01/pdf/chapter4.pdf>

the European Commission's DG Research FP5 and FP6 [30,31].

Scenarios are built on a series of new energy technology portfolios for the long term horizon, which encompass in particular:

- Hydrogen production through chemical, thermo-chemical or electrical routes
- Carbon Capture and Storage options to be used as add-ons in fossil-based power generation or hydrogen production generation plants
- A set of distributed electricity production systems with or without cogeneration, from fossil, renewable or hydrogen carriers
- Very Low Emission Vehicles with new power system and carrier concepts (in particular different types of electric and hydrogen cars)
- Very Low Energy Buildings with significantly improved thermal performances (Factor 2 to 4 reduction from conventional buildings in each region); provide positive energy buildings when combined with building integrated PV systems.

These portfolios and the technologies they contain have been selected both for their expected potential markets and for their intrinsic properties in particular in terms of environmental impacts. The projections in the different cost and performance categories (investment, O&M, efficiency, emission rates ...) have been organised in the dedicated database TECHPOL. This database allows to maximise the consistency of the exogenous hypotheses for the different time horizons and across the different technologies.

4.4 Reference scenario : key insights

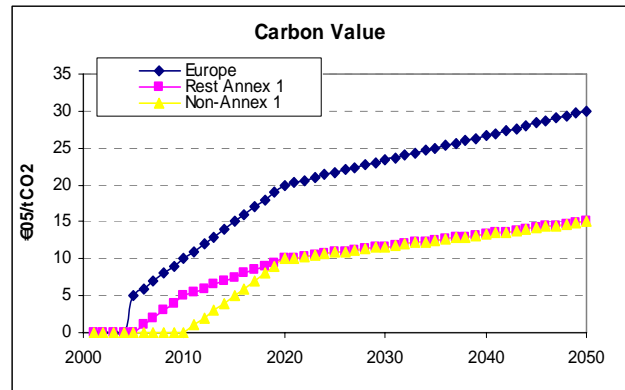
The design of the Reference case was developed as follows:

- Development of a Baseline case, i.e. the scenario that would correspond to an energy world developing on the basis of the pure economic fundamentals, without noticeable impacts of climate policies and nor of geopolitical constraints on world oil development.
- Introduction of a certain level of constraint on both emissions and oil development: i/ through the supposed extension of existing measures and ii/ through a higher degree of rigidity in world oil production capacity development.

The introduction of these political or policy constraints, which are indeed to be expected in future world energy development, enhances the realism of the Reference case, while on the contrary a pure Baseline would exhibit some hardly acceptable features.

In the Reference case, climate policies are simulated through the introduction of carbon values that are differentiated by region, with earlier and relatively stronger action in Europe (in conformity with other EU studies). Figure 1 shows the assumptions concerning the carbon value retained for Europe (from 5 €/tCO₂ in 2005 to 30 €/tCO₂ in 2050), other OECD countries (0-15 €/tCO₂) and the rest of the world (0-15 €/tCO₂).

Figure 8 : Carbon value in the reference case

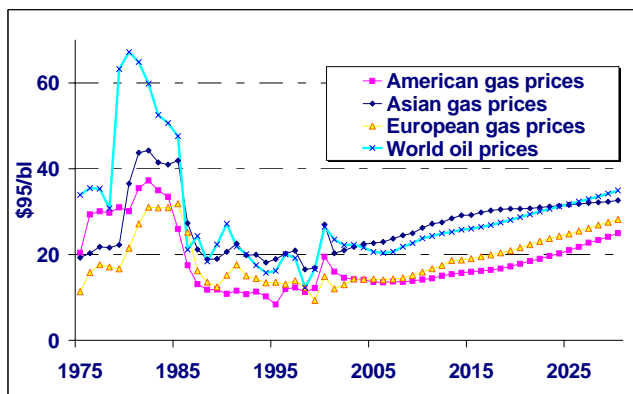


These values are intended to represent a minimum level of "Willingness To Pay for climate change mitigation policies" of each main regions of the world.

Whatever the future climate regime is and which value human community attributes to climate change risks and damages, there will be a mix of policies and a price attributed to CO₂ emissions in order to try to internalise the external costs.

In the WETO exercise, world final energy consumption is projected to grow by 1,8%/year on average during the 2000-2030 period of the simulation. With the current economic conditions, this reference scenario gives an important share to fossil fuels. Energy prices are expected to increase as shown in figure 9.

Figure 9 : Rising energy prices and past evolution

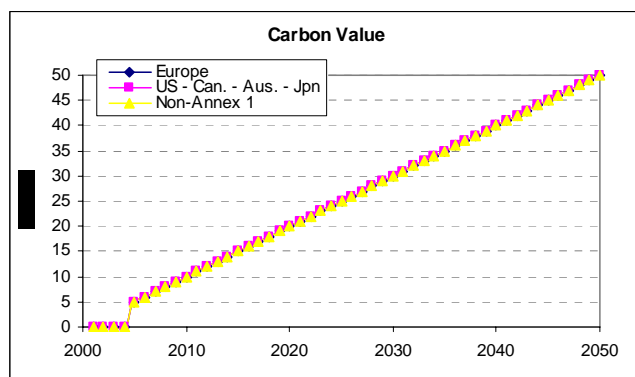


Source : POLES, 2003 [6] (note that foresight does not aim at "predicting" short term events such as oil prices rise)

4.5 Climate scenarios

In the first climate scenario, the cost of carbon is exogenous to the model and set to 10 €/tCO₂ in 2010 to 50 €/tCO₂ in 2050.

Figure 10 : Carbon value in the Increasing Carbon Value scenario



The second climate scenario aims to simulate more severe constraint, in line with UN Convention on Climate Change Final Objective and EU engagement of limiting average temperature increase to “less than plus 2°C, compared to pre-industrial level”⁶.

According to model-based estimates and projections, if no further action to control emissions is taken concentrations of greenhouse gas in the atmosphere may increase from 425 parts per million volume (ppmv) CO₂-equivalent today to 935 ppmv CO₂-equivalent in 2100.

The scenario studied in the ULCOS program corresponds to the Greenhouse Reduction Profile of S450CO₂, meaning the stabilisation of CO₂ concentration in the atmosphere at 450ppmv.

From preliminary work in the GRP study and different Multi-Stage endowment schemes, one can retain the following useful *orders of magnitude* on outcomes and requirements, displayed in figure 11.

Figure 11 : 2050 endowments compared to 1990 emissions

		2050 endowments compared to 1990 emissions	
Emission Profile	Temp. increase (median IPCC 2001 CSF) (INDICATIVE, see the discussion)	Annex 1	Non Annex 1
S550 CO ₂	+ 2.5 °C from Pre-ind + 1.9°C from today	/ Factor 2	X 2 (LAM, MET, SEEA) X 5 (AFR, SOA)
S 450 CO ₂	+ 1.6 °C from Pre-ind + 1.0°C from today	/ Factor 4	X 1 (LAM, MET, SEEA) X 3 (AFR, SOA)

Source POLES

4.6 On-going research

Steel technology dynamics

On-going research will link the POLES model with the sectoral equilibrium model of the steel industry, developed at IPTS [32].

The ISIM model projects the evolution of the steel sector in the period 1997-2050, paying particular attention to steel production, demand and trade, energy consumption, CO₂ emissions, steel technology dynamics, and retrofitting options. Industrial dynamics theories provide good insights on the conditions of adoption and diffusion of radical innovations under imperfect competition.

Evolution of the materials demand

Any reduction goal compatible with climate stabilisation will have considerable effects on economic activities, markets and behaviours. The demand side (in particular buildings and transportation) will be impacted, through their materials content. Work is under progress to simulate long term material demand [³³].

The steel industry has to anticipate long-term shifts in various economic sectors, which are more than likely in the context of climate change and resource depletion. Changes in the residential, services, transportation, agriculture sectors will imply different material demand in quality and quantity. One could think about the implication of changes in mobility or construction on the steel or aluminium demand.

Those questions will be explored in two sub-programs as stated in the Steel Strategic Research Agenda chain [³⁴]. Research program may consider how steel industry could benefit from a move towards the concept of Eco-efficient Services and systems change as a combination of technical change and societal change [35].

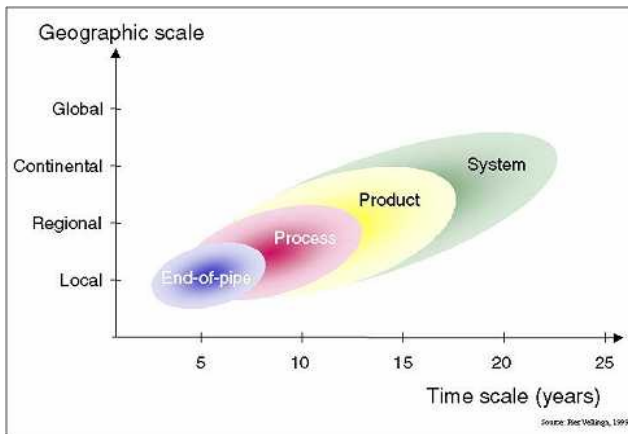
Systems innovation

The concept of systems innovation [36,37] and transitions to sustainability has increasingly gained attention over the past years in academics and policy arenas as transition to a far more low carbon world is needed. The attention has shifted from cleaner production to regime transformation, industrial transformation, technological transition, and socio-economic paradigm shift.

These three stages from end of pipe to product redesign and system changes illustrate the industrial transformation process which is arbitrarily estimated to take place along time scales on the order of 10 to 25 years. Figure 4 from the Industrial Transformation Science Plan [38] illustrates the relation between various response modes, the time scale, and the geographic scale involved.

⁶ For more on the scientific background, see the website of the scientific conference in Exeter <http://www.stabilisation2005.com/>

Figure 12 : Industrial transformation



Source [25].

Steel industry may be one of the key sectors to experience a thorough "industrial transformation" process. A growing literature aims at understanding the transformation of the structural characteristics of technological regimes along to environmental signals and ecological principles, reshaping entire trajectories of technological innovation [39] and shifting away from the current technico-economic paradigm [40].

5 CONCLUSION

Modelling systems allow to provide consistent images of the energy world with transparent hypotheses and the possibility to test alternative views on resources, technologies and policies.

The aim of this paper was to explain the methodology used to define the energy and climate scenarios as well as the main hypothesis that will provide the global framework for socio-economic analysis in the ULCOS project.

A broader range of factors than only energy / carbon prices are likely to affect technology diffusion. To be complete, the picture will also have to take into account the evolution of the world steel industry and industrial dynamics in the adoption of new technologies.

The dedicated module on steel industry (ISIM) coupled with the main POLES model will enable to explore the main future behaviour of the steel complex systems simply providing a clear view on the economic fundamentals of the inter-technology competition for steel-making in the future.

6 ACKNOWLEDGEMENTS

We would like to thank Silvana Mima, Philippe Ménanteau and Alban Kitous from the POLES team at Lepii-EPE and Enerdata as well as IPTS for their work on the model and in particular Ignacio Hidalgo for his work on the steel module ISIM. We thank members of ULCOS WP9.4 for their continuous inputs and discussion.

Research was made possible thanks to a PhD grant from ARCELOR and the French energy agency ADEME as well as ULCOS FP6 project.

All responsibility for the content rests with the authors.

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Annex

DEFINITION OF REGIONS WORLD BREAKDOWN INTO 7 REGIONS⁷



Western Europe: Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom

CEEC, CIS⁸:

- **CEEC (Central and Eastern European Countries):** Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, Poland, Romania, Serbia & Montenegro, Slovak Republic, Slovenia

- **CIS (Community of Independent States):**

Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyz Rep., Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan

North America: USA, Canada

Latin America: Central America (including Mexico), South America and Caribbean

Japan, Pacific: Japan, Australia, New Zealand, Papua New Guinea, Fiji, Kiribati, Samoa (Western), Solomon Islands, Tonga, Vanuatu

Asia: Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China, Hong-Kong, India, Indonesia, Lao, Macao, Malaysia, Maldives, Myanmar, Mongolia, Nepal, North Korea, Pakistan, Philippines, Thailand, Singapore, South Korea, Sri Lanka, Taiwan, Vietnam.

Africa, Middle East:

- **Africa:** North Africa (Algeria, Tunisia, Morocco, Libya, Egypt) and Sub-Saharan Africa

- **Middle East:** Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

⁷ The POLES model identifies thirty-eight world regions or countries, of which the 15 countries of the European Union and the largest countries (USA, Canada, Japan, China, India, Brazil, etc...).

⁸ This composite region is used because of lack of data by country for countries of the Former Soviet Union before 1992.