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Thirty-five Years of Long-run Energy Forecasting

Lessons for Climate change Policy

Jean-Charles Hourcade
Franck Nadaud

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Abstract

This paper sheds light on an implicit dimension of the climate policy debate: the extent to which supply-side response (emission-reducing energy technologies) may substitute for the transformation of consumption behavior and thus help get around the political difficulties surrounding such behavioral transformation. The paper performs a meta-review of long-term energy forecasts since the end of the 1960s in order to put in perspective the controversies around technological optimism about the potential for cheap, large-scale, carbon-free energy production.

This retrospective analysis encompasses 116 scenarios conducted over 36 years and analyzes their predictions for a) fossil fuels, b) nuclear energy, and c) renewable energy. The analysis demonstrates how the predicted relative shares of these three types of energy have evolved since 1970, for two cases: a) predicted shares in 2010, which shows how the initial outlooks for the 2000–2010 period have been revised as a function of observed trends; and b) predicted shares for t+30, which shows how these revisions have affected medium-term prospects.

The analysis shows a decrease, since 1970, in technological optimism about switching away from fossil fuels; this decrease is unsurprisingly correlated with a decline in modelers' beliefs in the suitability of nuclear energy. But, after a trend of increasing optimism, a declining trend also characterizes renewable energies in the 1980s and 1990s before a slight revival of technological optimism about renewables in the aftermath of Kyoto.

This paper—prepared as a background paper to the World Bank's *World Development Report 2010: Development in a Changing Climate*—is a product of the Development Economics Vice Presidency. The views expressed in this paper are those of the authors and do not reflect the views of the World Bank or its affiliated organizations. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at nadaud@centre-cired.fr.

Thirty-five years of long-run energy forecasting: Lessons for climate change policy

Jean-Charles Hourcade
Franck Nadaud[1]

CIRED (Centre International de Recherche sur l'Environnement et le Développement / International Research Center on Environment & Development, France)

&

SMASH (Société de Mathématiques Appliquées et de Sciences Humaines / Society of Applied Mathematics and Humanities)

Background Paper for the *World Development Report 2010: Development and Climate Change*

[1] Corresponding author : Franck Nadaud (nadaud@centre-cired.fr). Dr. Jean-Charles Hourcade is Research Director at CNRS (Centre National de la Recherche Scientifique / National Center For Scientific Research) and is the scientific director of CIRED. Franck Nadaud is a Researcher at CIRED. Both authors are also affiliated with SMASH, a research organization closely linked to CIRED.

Introduction

One of the implicit dimensions of the climate policy debate is the extent to which supply-based responses may substitute for demand-side efforts. These efforts indeed are perceived as requiring transformations of individual and collective behaviors, and technological optimism on the decarbonization of the energy supply is a way of getting round the political difficulties of demand-side policies.

The difficulty in evaluating the potential of supply-side responses is that, at any point in time, any such assessment depends on technological forecasts which are necessarily self-fulfilling in nature. But at the same time, the forecasts are indicative of the global outlook that prevails when they are elaborated.

Therefore, in order to put into perspective the controversies between technological optimism and pessimism, the following meta-review performs a retrospective analysis of past (and recent) forecasts to reveal the long-run trends in the outlook of experts about the potential of future energy options to go out of fossil based energies. It conducts a comparative assessment of world and US energy forecast studies. The main reason why the US is singled out is that US-focused studies are the only ones whose geographic scope does not vary from year to year. For example, in the global studies, Japan is alternately aggregated with the "rest of OECD" or with other industrialized Asian nations. Furthermore, the definition of Europe varies across studies and over time from six member states to twenty-seven today.

A total of 32 studies have been selected,[2] encompassing 116 scenarios in which we compute the relative shares of primary energy in three groups of primary energy sources:

- nuclear energy;
- renewable energy (RE), excluding biomass and traditional energy;
- fossil fuels.

All studies deliver a finer level of detail on renewable energies (e.g. biomass, hydraulic or wind) and on the breakdown of primary energy from different sources (coal, oil, gas). A more aggregate analysis is unfortunately needed to secure the comparability of a larger sample of studies. But the price to pay for this aggregation is not so high, given that what matters is less to describe the precise composition of the energy portfolio than to capture the structural expected shifts in the primary energy supply, with a focus on fossil fuels and within the substitutes to fossil fuels the main and politically sensitive difference between nuclear energies and other carbon free energies.

The main challenge in comparing studies conducted over a period of about 36 years is that their forecasts cover different time periods. To overcome these difficulties and make the best use of the material we defined two presentation modes:

(1) Relative shares in 2010: We interpolated (and extrapolated for the few studies of the early seventies which very often covered year 2000) the projected values in each study for 2010. This date made it possible to use the maximum of carried out studies with the same

[2] A list is given in the annex.

target year of 2000, which allows for comparison with the studies carried out in later years that forecasted beyond 2010.

(2) Relative shares in t+30 years from the year of reference in each study: This indicator allows for capturing the implementation lag of any major energy policy shift, given the diffusion/maturation period of the underlying technologies. How the t+30 indicators evolve made it also possible to assess the trends for a given technical change (i.e., 30 years ahead).

The first section presents our chosen methodology and details of the data processing step. Section two presents our main results, with the support of detailed graphs. Section three derives some general lessons of interest in the reflection about the nature of any energy forecast.

1) Methodology

In this section we describe the method used to compute the results. Note that this study comes along with a data spreadsheet file that may allow the reader to reproduce our results or work out their own.

1.1) Energy unit conversion

Different scenarios often use various energy units. For example, US scenarios most often use the Quadrillion BTU (Quad), or sometimes the Million Barrel per Day (mbd), while the Shell company scenarios use Exa Joules, and the book *Energy for a Sustainable World* uses a seldom used unit related to generation capacity (i.e., Tw.yr). For comparison purposes it was deemed preferable to convert the original scenarios' energy units into a unique and homogeneous unit. Therefore, all energy units were converted into Million tons of oil equivalent (Mtoe) using conversion coefficients from the American Physics Society website[3] which is retained in the IEA's annual World Energy Outlook reports results in Mtoe and in the IPCC emission scenarios.

1.2) Scope of scenarios and use of median shares

The different studies provide a set of contrasted scenarios. Instead of picking a few scenarios in each of them more or less arbitrarily, we retained all of them when possible.[4] However, we took the median shares across all the recorded scenarios (i.e., primary energy shares for nuclear, RE and fossil fuels, in 2010 and t+30). This avoids the drawback of conferring to each study a weight directly proportional to its number of alternative scenarios and to increase the results variance as a simple consequence of the fact that computation capabilities increased over time, as did the belief that the objective of energy forecasting lies less in predicting the future than in clarifying the field of possibilities.

The motivation for using the median share stems from the fact that it is a more robust statistic than the conventional arithmetic mean. Concerning the SRES scenarios, we considered not the

[3] http://www.aps.org/policy/reports/popa-reports/energy/units.cfm

[4] It was found that some studies do not display usable figures for our purpose, or that they provide scattered, crude information. In this case, the results were not used.

whole set of scenarios published around each basic storyline, but results from the six marker model runs carried out by the core teams involved.

1.3) "Stick to the data as much as possible"

We report the original values whenever they are available if they correspond to the year 2010 or the year t+30 in the original scenario. When this value is not available[5] we interpolated it. In both cases, shares for 2010 are then computed for all the recorded scenarios and a median energy portfolio share is computed across all the scenarios and for each of the three energy sources (nuclear, RE and fossil fuels).The same procedure is applied to t+30 figures.

1.4) Extrapolate the real trajectories of primary energy consumption

Where extrapolations or interpolations are needed, growth rates were used for each separate primary energy component. Thus, each component is then allowed to grow to the target year at its own rate based on explicit or implicit growth trends.[6] Then all components are totaled and shares are computed for the given year.

1.5) Retain the broadest primary energy base possible

Energy studies do not always report the same total primary energy consumption. The most important difference lies in whether the study incorporates biomass and traditional energies: commercial energy only without biomass, commercial energy + biomass, commercial energy and total traditional energy. In all cases we use the broadest definition of primary energy originally presented in the scenarios. This means that when traditional energy and biomass are present, we use the total primary energy consumption including them to compute the shares to 2010 and t+30. This leads to the last step of our methodology.

1.6) Special attention to renewable energy

The renewable energy shares displayed are defined in a narrow sense: excluding biomass, waste and traditional energy. Obviously, under this narrow definition, the share of RE in primary energy consumption will be lower. Note that this narrow definition essentially covers the market-oriented RE systems like solar, wind or hydraulic RE. On some occasions it was not possible to compute the narrow RE share from available data, so the figures originally reported in the studies are given. Finally, most scenarios (especially the older ones) do report very broad categories of RE technologies like hydraulic, other RE and biomass + traditional energies. We always stick to the original level of detail, according to the policy of section (1.3).

[5] In the Energy for a Sustainable World IIASA scenarios, there are two scenarios and two variants. Unfortunately, the two variants are not as detailed as the reference scenarios, we decided that for the two variants, the trajectory was the same up to 2000 and diverged after.

[6] That is, for in-between years, we used the average growth rate between these two years; for out-of-sample years, we extrapolated from the past growth path. This latter approach was frequently applied to older scenarios whose forecasts are often just to the year 2000.

2) Synthesis of the results; two perceptible trends and a “noise”

The results of our investigation are reported as a gallery of graphs depicting various exploratory visualizations of the data. The full set of data is given in table 2 in the annex.

The graphs are scatter plots of the projected energy portfolio for all scenarios as a function of the *year of publication* which appears on the horizontal axis for all the graphs. A scatter plot is given for each energy source’s share both for 2010 and t+30. Additional graphs help detecting trends in expectations. In those plots, the same symbols represent each energy forecasting project so that a project may be easily identified in the graph. Choosing the date of publication as the abscissa is the key step to reveal the change over time of the experts’ outlook for the future.

The data depicted in the graphs are given in table 2 of the annex of this document. Graphing all the scenarios would have the advantage of comprehensiveness. For reasons given above, we report the median shares for each study, across its various scenarios – except for the IPCC SRES scenarios. For the latter, we report the median shares for each of the six different energy models. For each energy source we report sets of four graphs. The first covers both 2010 and t+30 and displays energy projects with symbols, and distinguishes studies focused on the US by depicting them as squares of different color. A second set does not distinguish by source or geographic coverage and focuses on uncovering trends in the forecasted shares according to the date of publication, for both 2010 an t+30.

2.1) Fossil energy: the resilience of growing trends in market shares

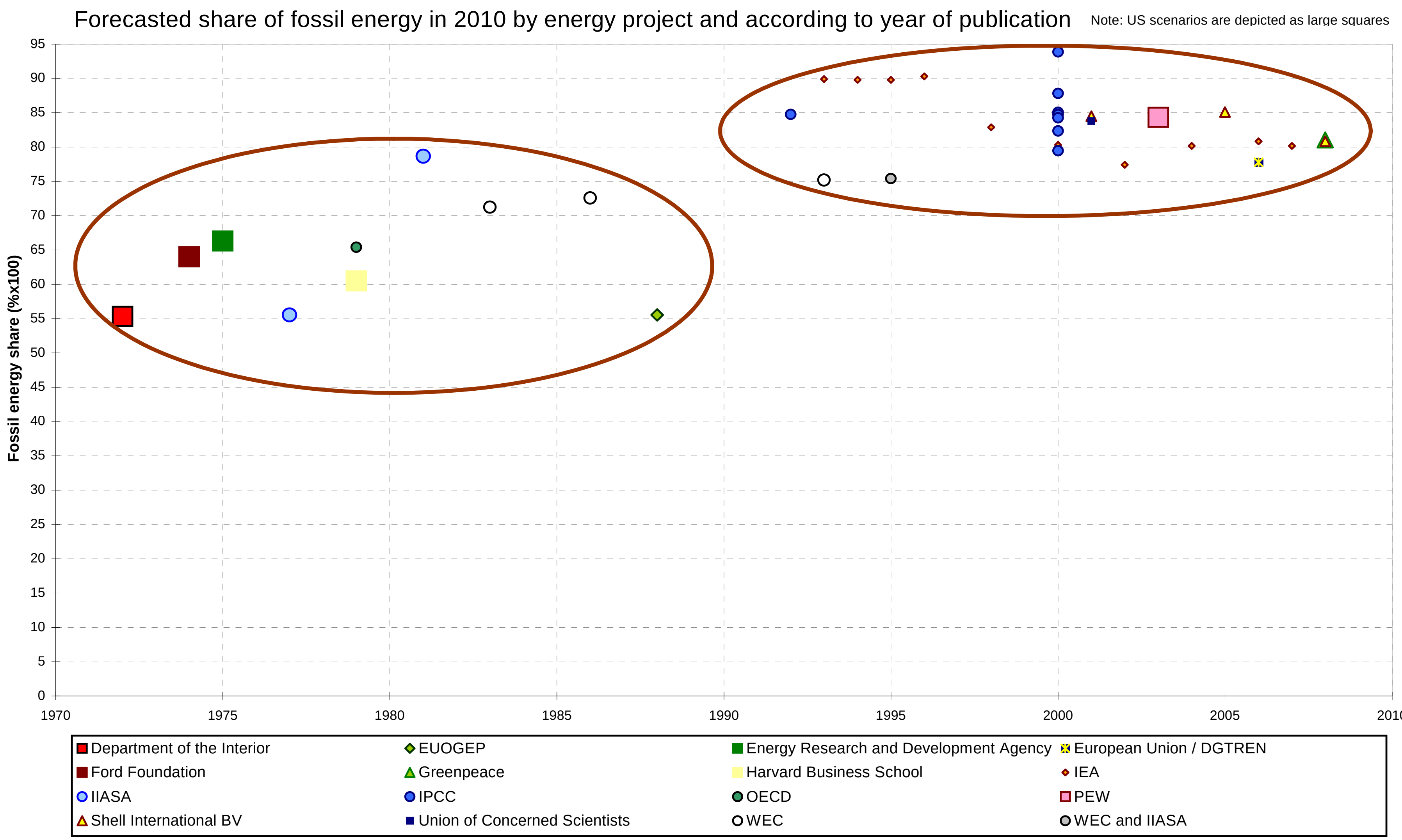
In figures 1 and 2, the median fossil energy shares are displayed for 2010 and t+30 for all the energy studies considered.

This statistic gives an aggregate measure of the changing technological optimism regarding our ability to substitute away from fossil energy. As time passes, projections are less and less optimistic: studies published in the 1970s envision fossil fuel shares between 55% and 65% of primary energy, whereas those published in the 1990s show an increase in the projected share of fossil fuels, leading to a convergence of forecasts of the fossil fuel share around 80%.

This result, as will be seen in the following section, is largely due to the downward-creeping assessment of the potential for nuclear energy and this is confirmed in figure 2 where we show the evolution of the predictions at t+30 years from the reference year.

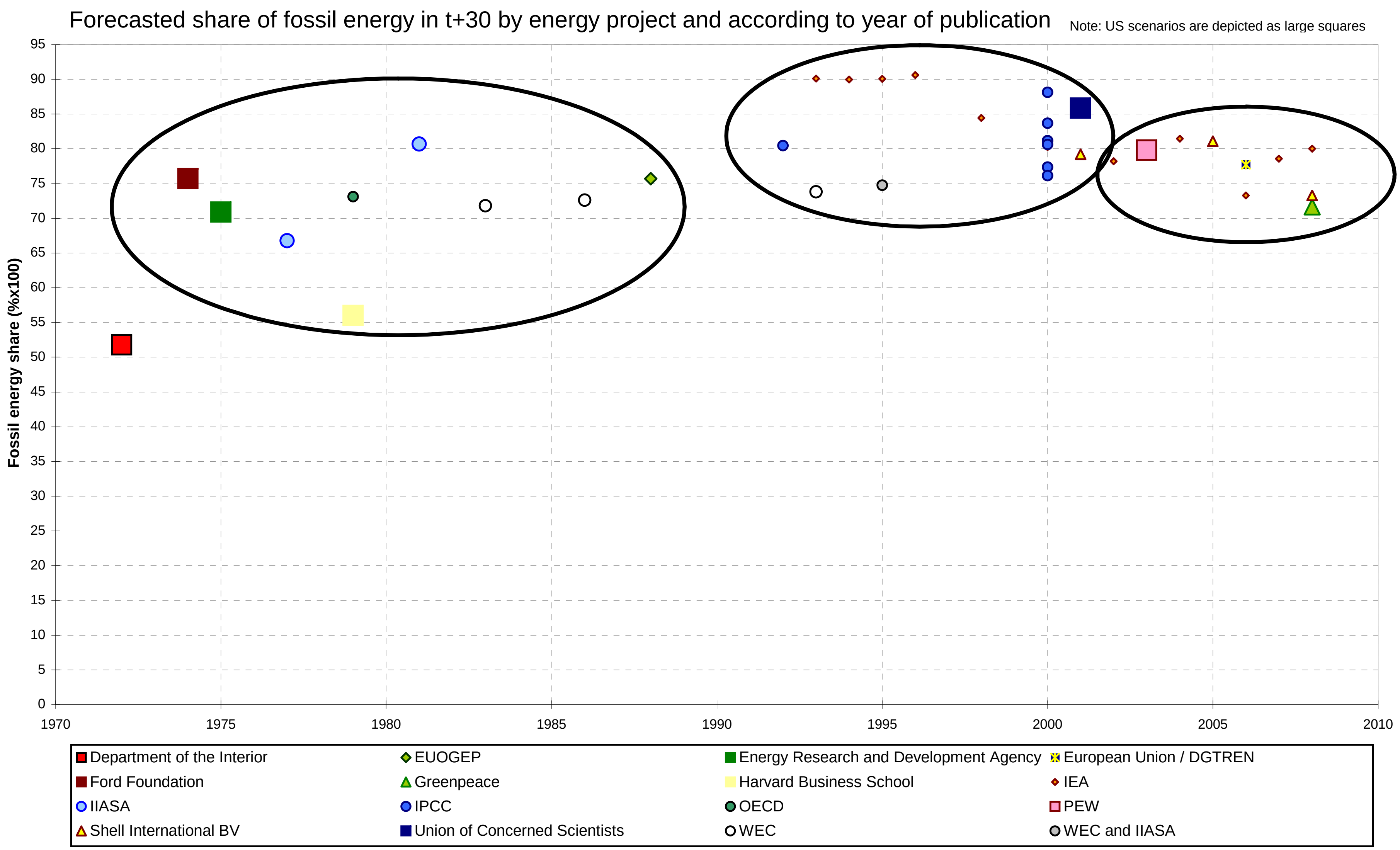
After 1990, we witness a quasi stabilization of projections of the fossil fuel primary energy share in t+30 (figure 2) between 70% and 90%. But, in forecasts published starting from 2000, just after the signing of the Kyoto Protocol, one can see a return to a greater optimism, though it is still modest, with estimates of decarbonization only in the range of 20% to 30%.

Figure 1



Forecasted share of fossil energy in 2010 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
Fossil energy share (%x100)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

Figure 2



Forecasted share of fossil energy in t+30 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
Fossil energy share (%x100)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

Figures 3 and 4, for both 2010 and t+30 respectively, help to sketch out a more broad-brush view of the trends. To show out these trends we first used a regular linear regression line (in solid red) along with the regression equation (shown next to the graph legend) and in a second step we added an interpolation (the thin dashed black line) by a robust Tukey smoother.[7] This smoother is robust in the sense that it is insensitive to outliers, unlike the common linear regression line. In addition, the Tukey smoother provides insights about the existence of any trend in the data, as well as the trend's nature (linear or not), while allowing a quick assessment of the degree of linearity present in the data. John W. Tukey designed it as one of the many easily computed statistics of the Exploratory Data Analysis (EDA) methodology aimed at revealing patterns in data (Tukey, 1977).

The increase in the fossil energy share is shown by both trend lines. Concerning the linear regression, the fit is moderate ($R^2 = 0.51$) but significant. Meanwhile the Tukey smoother is not far from the regression line. However, contrary to the linear regression line whose slope is by construction constant, the Tukey smoother tells a two-period story: a gradual increase of the fossil fuel shares up to the early 1990s, followed by a peak around 1995, and then followed by a gradual decrease: the peak share dropped from 90% to 8 % in the most recent studies.

The upward (i.e., increasingly pessimistic) linear trend is still visible but far less pronounced than in figure 3 ($R^2 = 0.25$) because of the more scattered set of forecasted fossil fuel shares in t+30, as compared to the 2010 forecasts. The same remark about the regular regression and Tukey smoother trends apply here.

[7] It very clearly shows a trend towards pessimism that accelerates in the middle of the 1980's and then reverses in the post Kyoto years.

Figure 3

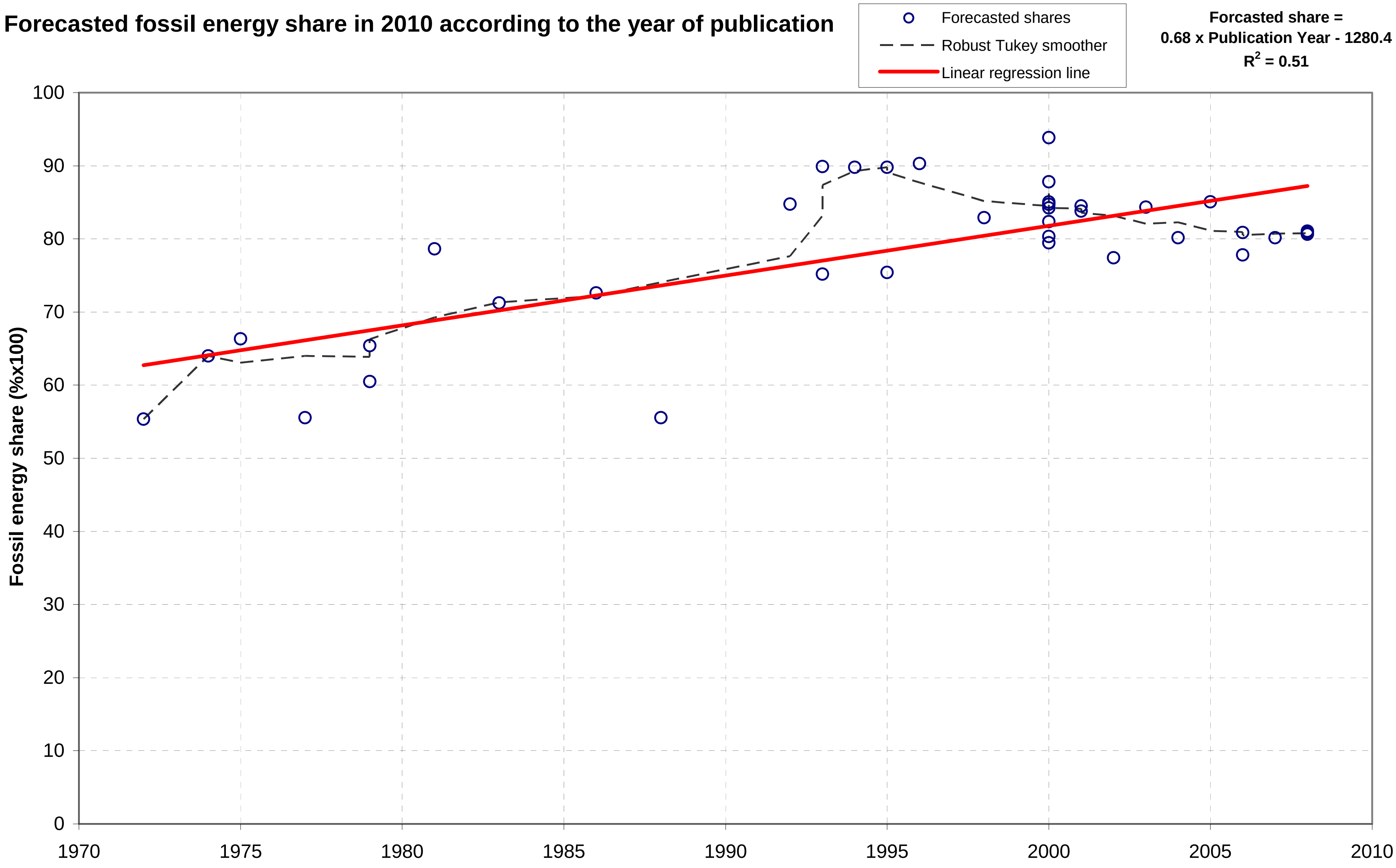
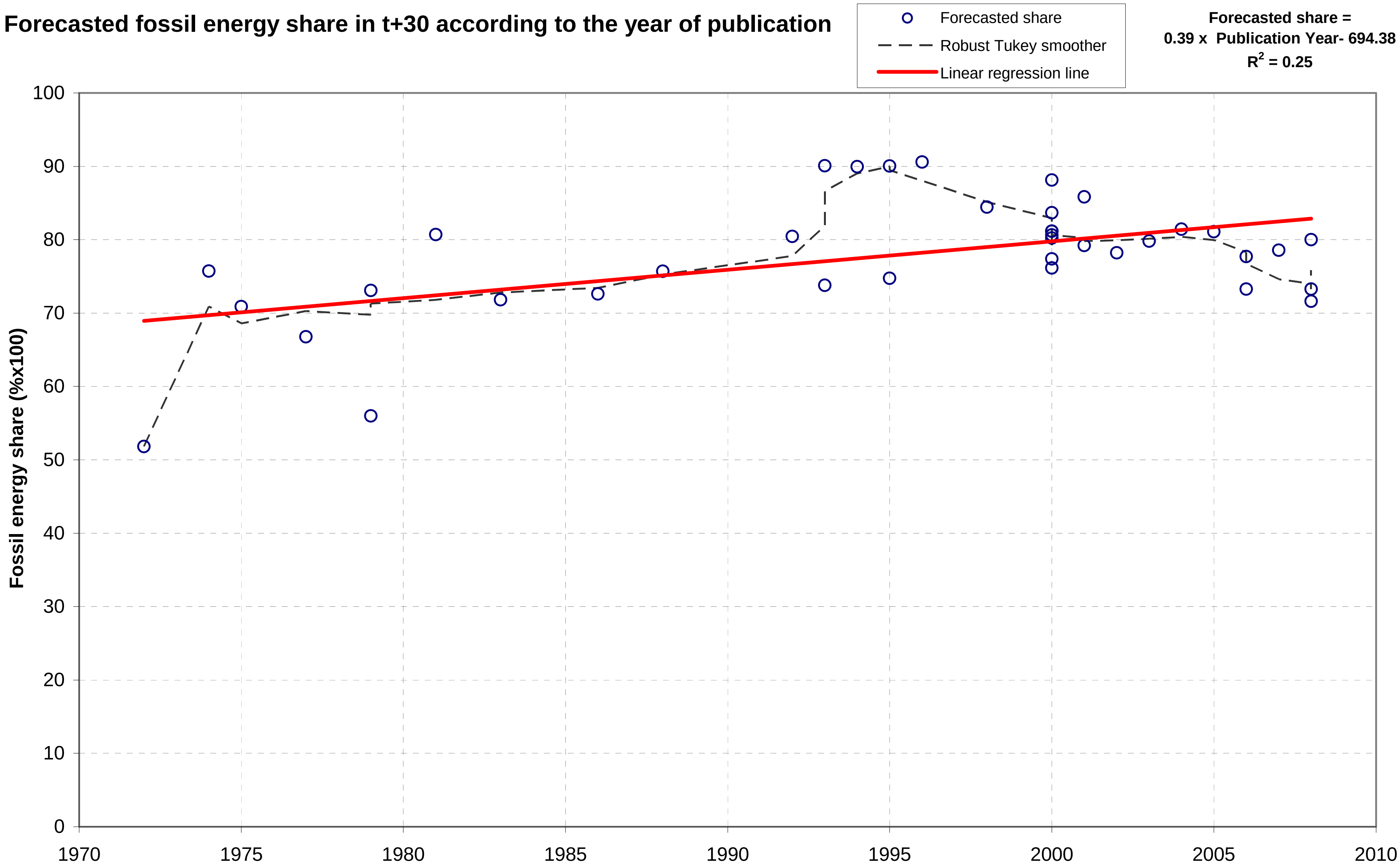

Forecasted fossil energy share in 2010 according to the year of publication
Forecasted shares
Robust Tukey smoother
Linear regression line
Forcasted share =
0.68 x Publication Year - 1280.4
R2 = 0.51
Fossil energy share (%x100)
0
10
20
30
40
50
60
70
80
90
100
1970
1975
1980
1985
1990
1995
2000
2005
2010

Figure 4



Forecasted fossil energy share in t+30 according to the year of publication
Forecasted share
Robust Tukey smoother
Linear regression line
Forecasted share =
0.39 x Publication Year- 694.38
R2 = 0.25
Fossil energy share (%x100)
100
90
80
70
60
50
40
30
20
10
0
1970
1975
1980
1985
1990
1995
2000
2005
2010

2.2) Renewable energy: a persistent noise

The striking feature in the evolution of renewable energy (RE) shares in figures 5 and 6 is the persistence a very large dispersion of the results in all years even when we only use the median shares of each study.

One can certainly register in the t+30 scatter plot an increase of both the level and variance of the projected RE shares, together with, remarkably, great stability over time in the pessimistic results (e.g., IEA estimates through the 1990s and 2000s) and, on the other hand, an increase in the upper bounds of the projections (e.g., Shell International). To try and discern some trends in this almost shapeless set of data points, we report again in figures 7 and 8 the linear regression line and the robust Tukey smoother, for 2010 and t+30.

The linear regression shows an absence of time correlation ($R^2 \sim 0.0$) for the 2010 projections and an almost insignificant one for the t+30 projections, ($R^2 = 0.12$) and twice as low as the t+30 fit for the share of fossil fuels ($R^2 = 0.25$, figure 4).

In fact, the seeming trend towards more optimistic views about RE (whereas this trend was downward oriented for the 2010 time horizon) might well simply result from an increase over time in computational capacities and the growing tendency of studies to explore more in depth a wider range of contrasting scenarios.

The robust Tukey smoother, although confirming the absence of clear trends allows for sketching interesting indications. For the 2010 scatter plot, an upward trend culminates in the RE shares of studies published in the 1980s, followed by a downward revision of the forecasts for RE in the studies published in the 1990s, before a sudden surge in optimistic scenarios around 2000 and a subsequent decline around 2006.

The similarity of these 2010 and t+30 dotted lines seems to clearly indicate a lagged correlation in technological beliefs with the oil price movements: studies published in 1983-1985 have been launched during or just after the second oil shock and studies published in the nineties have been launched during a period of low oil prices. Studies published in 2000 seem to be influenced by the Kyoto Protocol which spurred optimism about carbon free energies.

Figure 5

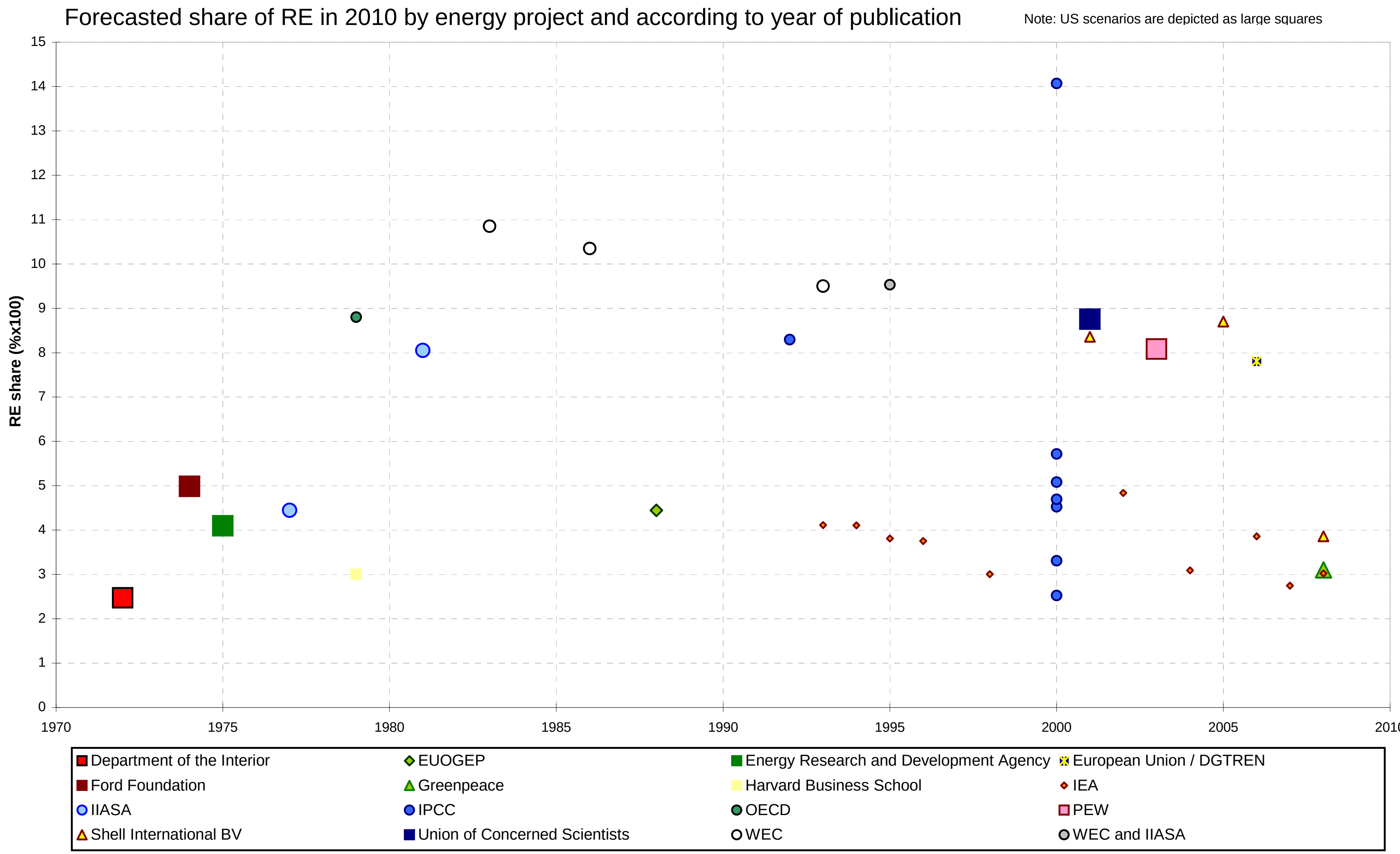

Forecasted share of RE in 2010 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
RE share (%x100)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

Figure 6

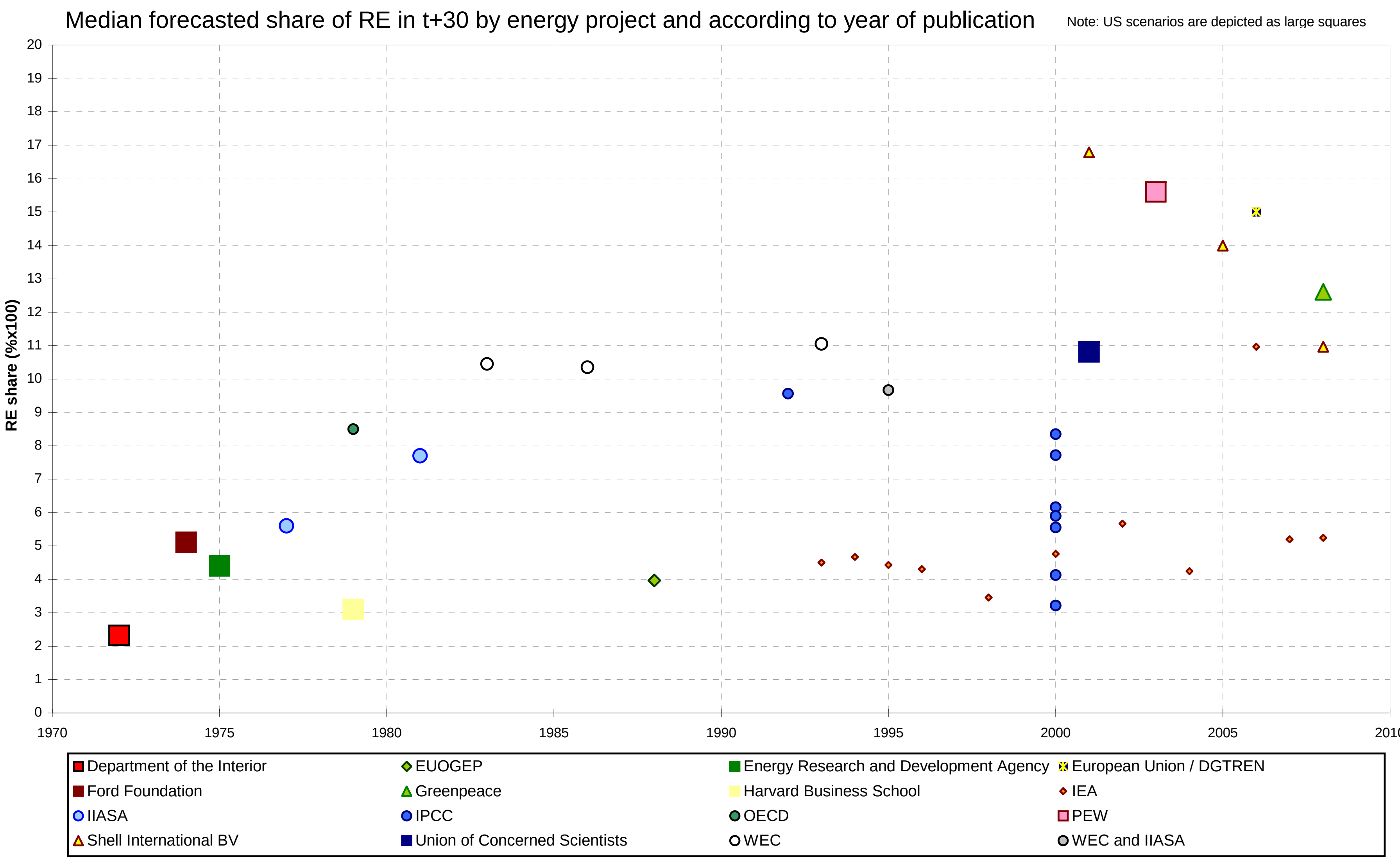

Median forecasted share of RE in t+30 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
RE share (%x100)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

Figure 7

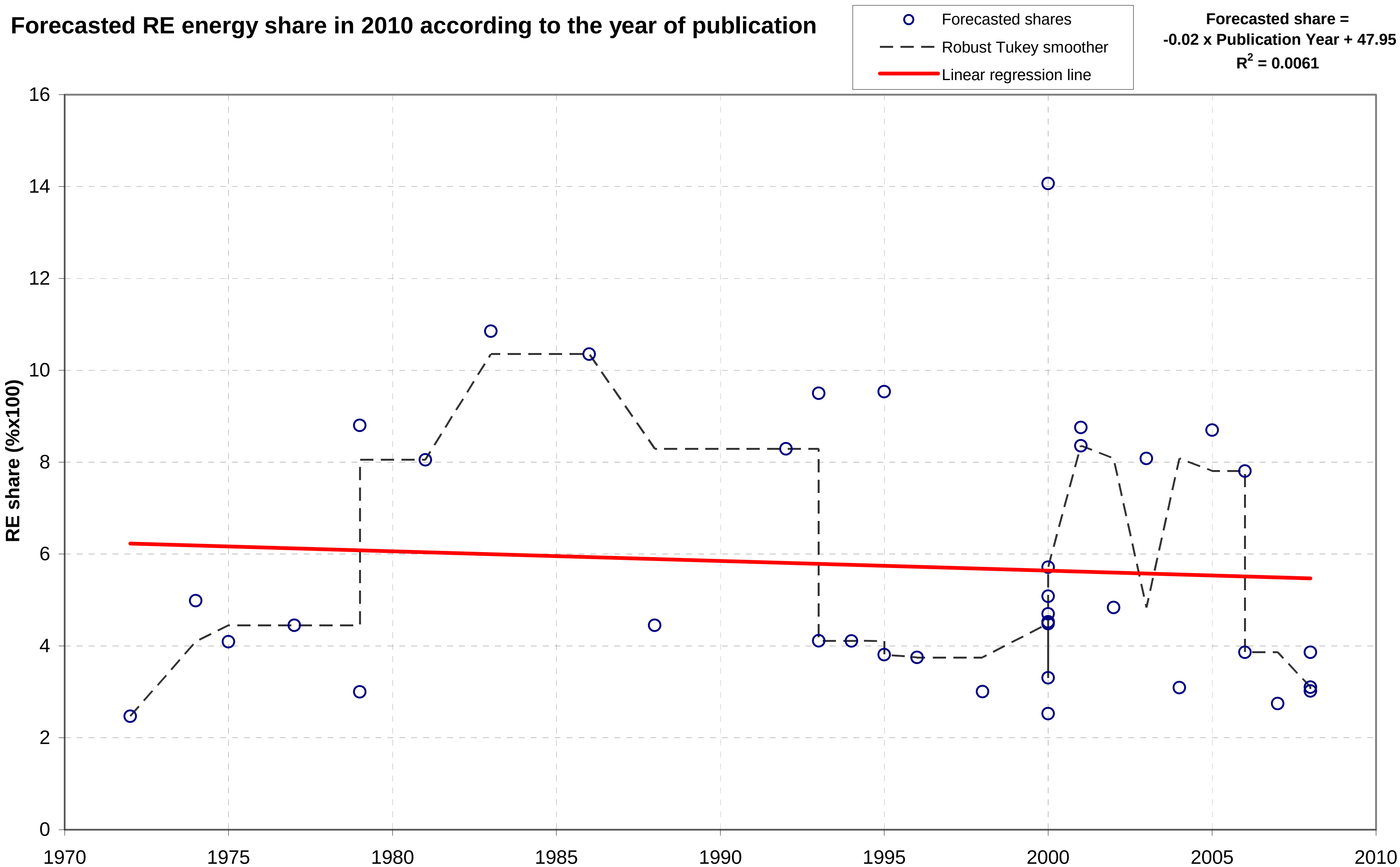
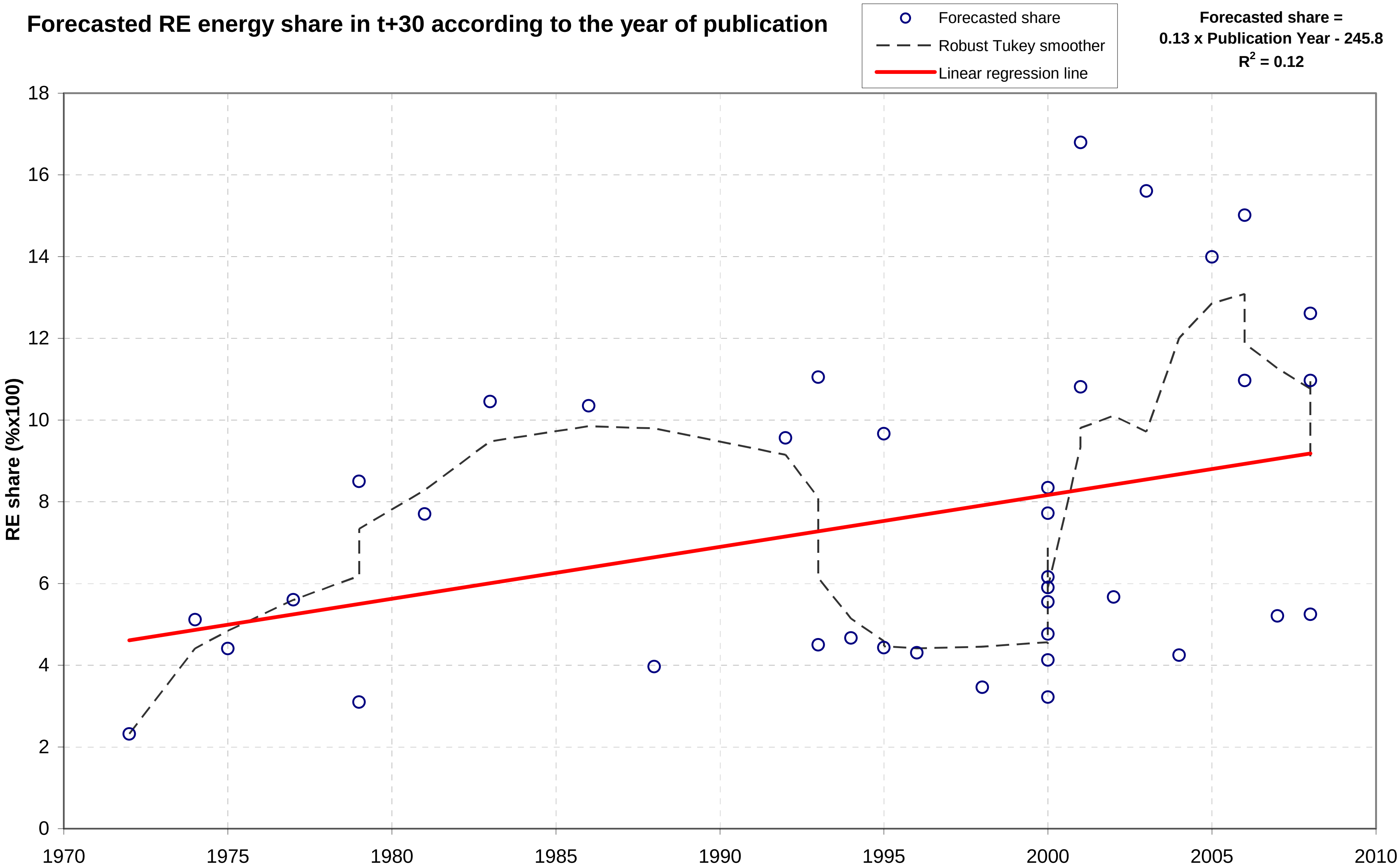

Forecasted RE energy share in 2010 according to the year of publication
Forecasted shares
Robust Tukey smoother
Linear regression line
Forecasted share =
-0.02 x Publication Year + 47.95
R2 = 0.0061
RE share (%x100)
0
2
4
6
8
10
12
14
16
1970
1975
1980
1985
1990
1995
2000
2005
2010

Figure 8


Forecasted RE energy share in t+30 according to the year of publication
Forecasted share
Robust Tukey smoother
Linear regression line
Forecasted share =
0.13 x Publication Year - 245.8
R^2 = 0.12
RE share (%x100)
0
2
4
6
8
10
12
14
16
18
1970
1975
1980
1985
1990
1995
2000
2005
2010

2.3) Nuclear energy: an unsurprising downward reassessment

Let us now turn to nuclear energy, which was viewed in the early 1970s as the most likely large scale substitute to oil.

Both figures 9 and 10 confirm the technological optimism of the 1970s about nuclear energy. The early US forecasts may seem extreme but the forecasted nuclear share is also quite high for worldwide energy studies of the same period: IIASA and OECD projected a median share of nuclear energy in 2010 of 40% and 25%, respectively, and though for t+30 the shares forecasted by IIASA and OECD are far lower than the US studies', they are still quite high. This optimism for nuclear energy gradually fades during the 1980s, stabilizing during the 1990s at around 5% of primary energy. Whereas we just saw that there is large variation between 2010 and t+30 for fossil and renewable energy, we can note for nuclear a remarkable convergence of the forecasted shares: from 1990, a consensus emerges around 5% for both 2010 and t+30.

The linear regression gives a reasonable fit but which is less informative than the Tukey smoother indicator which shows out, unsurprisingly for those who know about the history of the debates about the non-military uses of nuclear energy, two distinct periods: the first period encompasses the 1970s and 1980s, when the projected shares of nuclear fall sharply. The second period starts at the end 1980s when the trend is totally flat, i.e., around a stable consensus level which only translates the feeling of a continued ban of this energy in many parts of the world.

The same conclusions hold for t+30 with the notable difference that the linear fit is less steep due to a greater dispersion in this scatter plot. The two periods described in figure 11 seem to be magnified in this figure: there is more dispersion in the first period and less in the second. The decreasing slope of the linear regression lines is thus less in absolute value: 0.71 vs. 0.81 in figure 11. The fit is moderate in both figures ($R^2 = 0.64$ and 0.63, respectively) but acceptable.

Figure 9

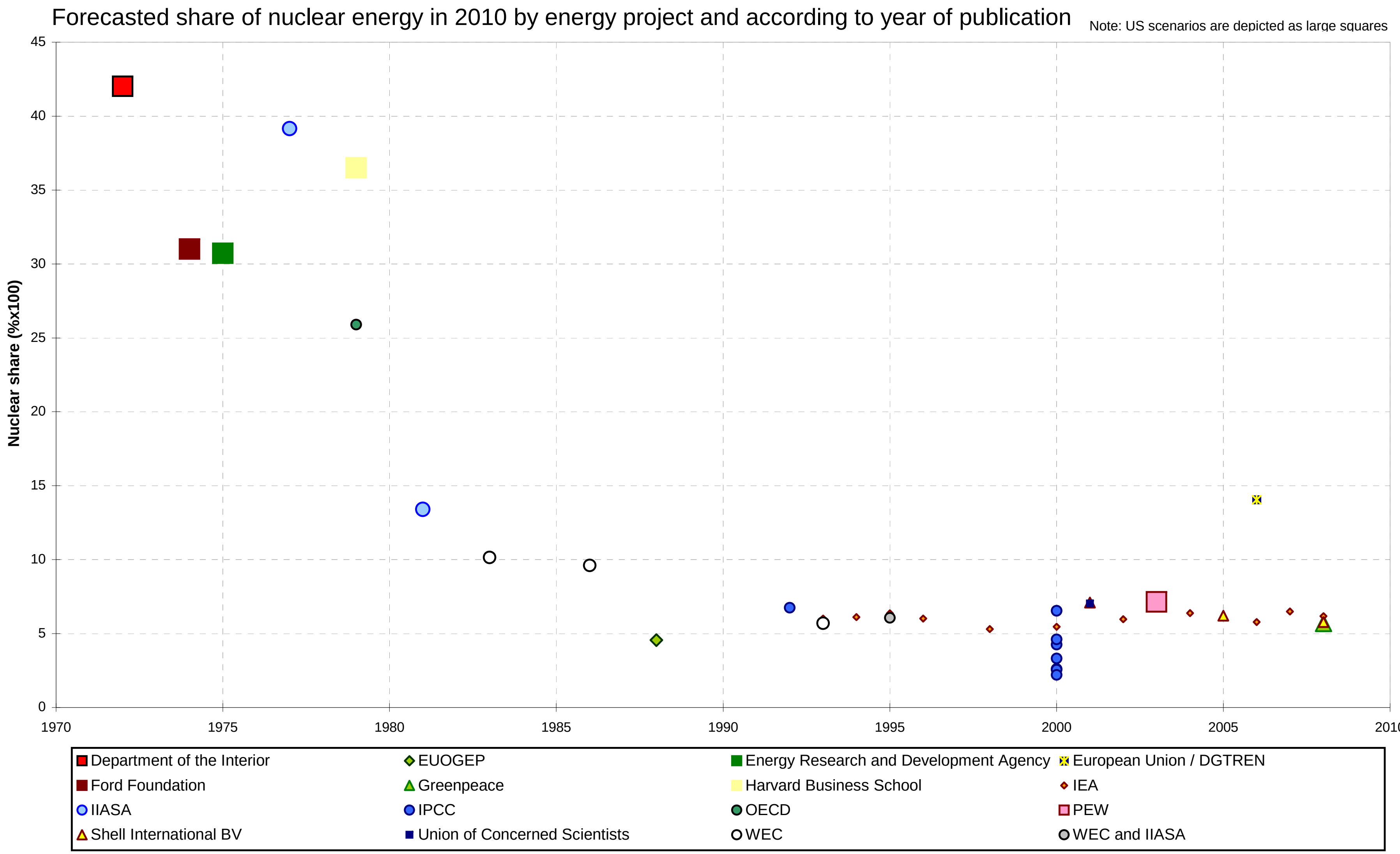
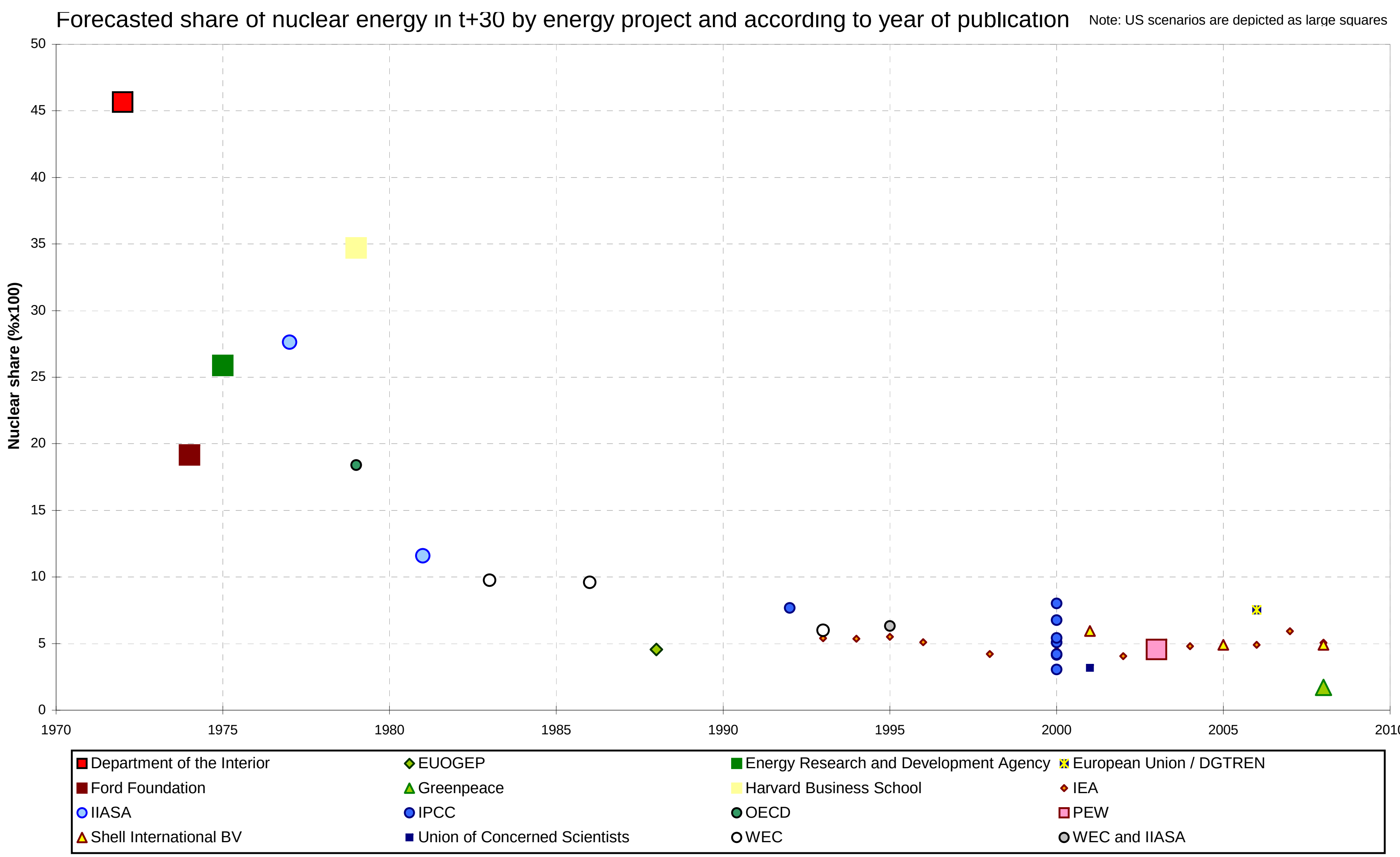

Forecasted share of nuclear energy in 2010 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
Nuclear share (%x100)
0
5
10
15
20
25
30
35
40
45
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

Figure 10



Forecasted share of nuclear energy in t+30 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
Nuclear share (%x100)
0
5
10
15
20
25
30
35
40
45
50
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

Figure 11

Forecasted nuclear energy share in 2010 according to the year of publication

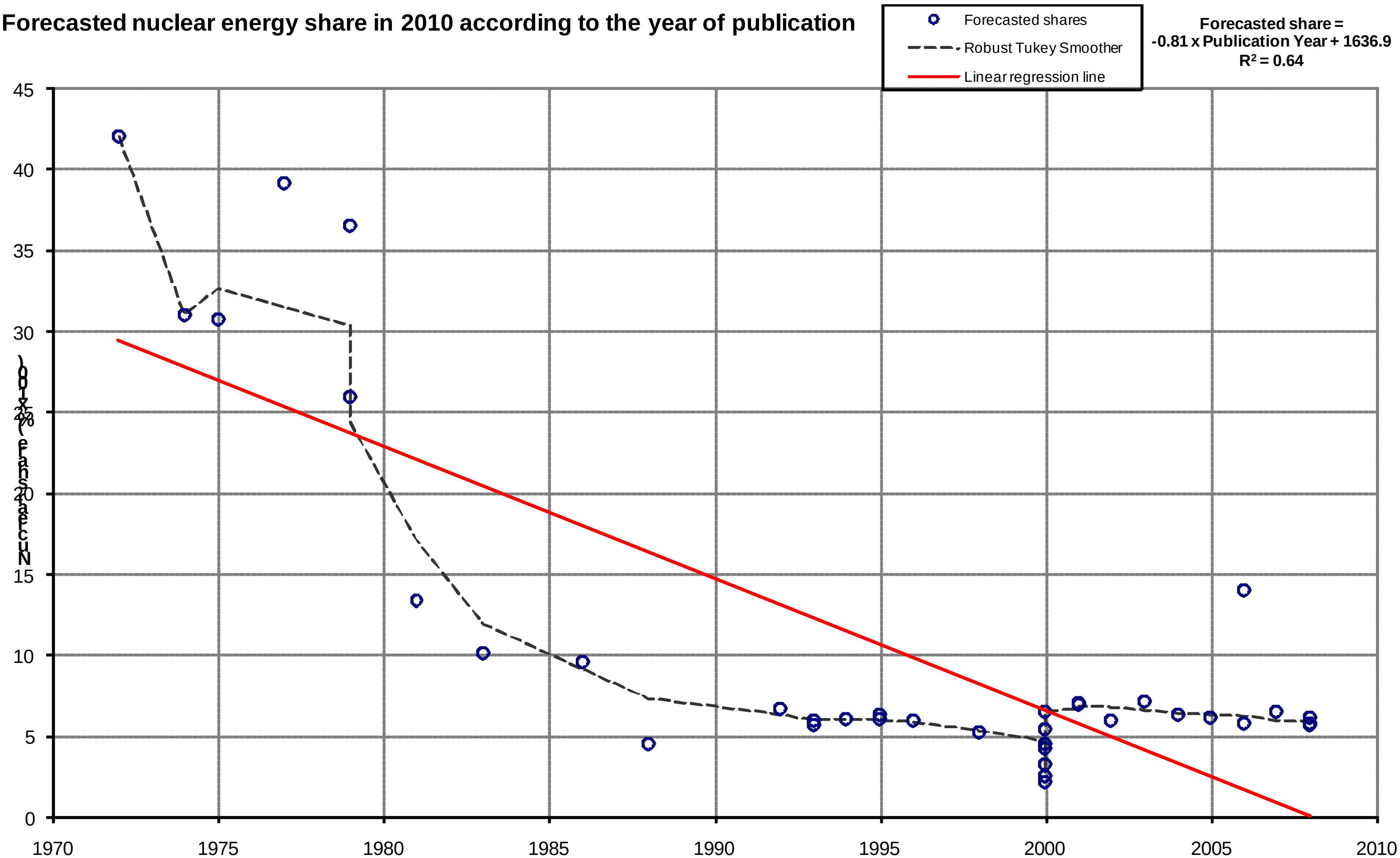
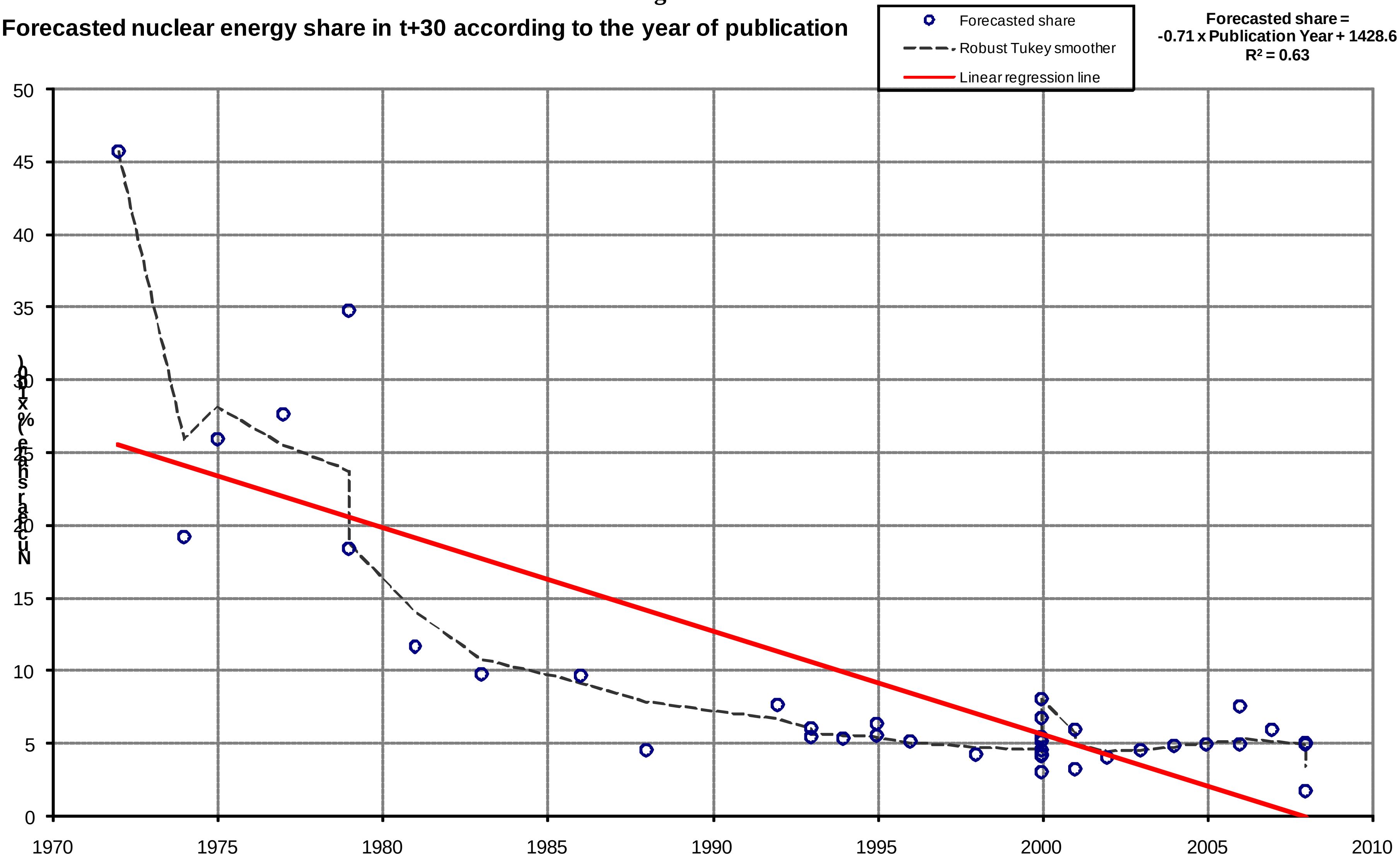


Figure 12

Forecasted nuclear energy share in t+30 according to the year of publication



3) Discussion and conclusion

The preceding analysis of 37 energy forecasting studies and their 116 scenarios shows how long-term visions of the structure of the energy supply evolved over a period spanning almost 35 years. The first striking feature is that the 1970s technological optimism about our ability to switch away from fossil fuel (fossil fuels were projected to have only a 50-70% share in total primary energy at t+30) decreased significantly in the 1990s (a share of 75-90%), likely influenced by the long period of relatively low oil prices after 1985. The slight recovery of optimism in the last 5-10 years (70-80% share of fossil fuels) seems correlated with the rise in oil prices. A potential change in worldviews after Kyoto seems very low up to 2005, a logical consequence of the Bush administration's neglect of Kyoto (figure 13).

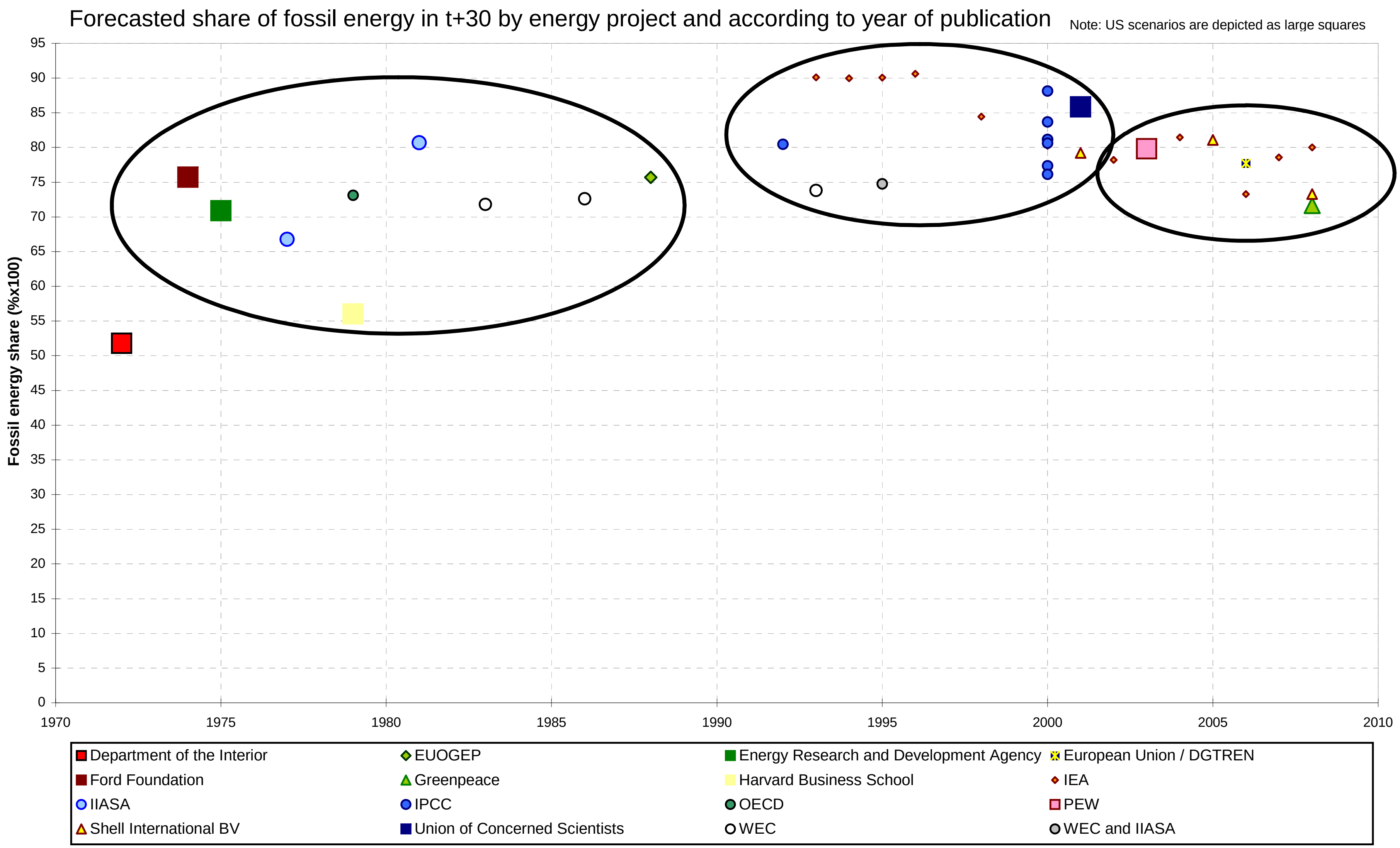
The decline in technological optimism is unsurprisingly correlated with a decline in modelers' belief in the suitability of nuclear power, with projections of the share of nuclear power dropping from a high of 20-35% in the 1970s to around 5% in the last two decades (figure 14). This decline shows that modelers internalized public concerns about nuclear power and did not envisage a reversal of public opinion; furthermore, the period of low oil prices after 1985 did not offer a strong argument that the economic advantage of nuclear power outweighed the concerns.

The case of renewable is more intriguing as a trend of increasing optimism from the early 1970s to the mid 1980s (with the share rising from about 2% to 10%) was followed by a period of great uncertainty, as shown by the subsequent large range in projected shares (4-12%, figure 15). Also, a group of renewable optimists has emerged in the last decade predicting a higher share of renewables in the next 30 years. The influence of Kyoto, which was not significant for fossil fuels and nuclear, is more clearly detectable for renewables, with more optimistic studies launched in the late 1990s and published in 2001 and 2003. The rise in oil prices supported this reassessment of the role renewable energies but no study predicts a drastic acceleration of their penetration.

The apparent conservatism that emerges from this retrospective is a message to be considered in debates around climate policies. Indeed, whereas the relative stability of the structure of the energy supply over thirty years is not surprising given the inertia of energy systems, here we investigate long-term visions of the world, and technical inertia cannot explain why the projected prospects for shifting away from fossil energies have been so stable since the early 1980s. Historically, the promises of generous technical change on the supply side were not fulfilled in the case of the nuclear energy, nor in the case of new and renewable energies, for which projected shares were not upgraded during more than three decades.

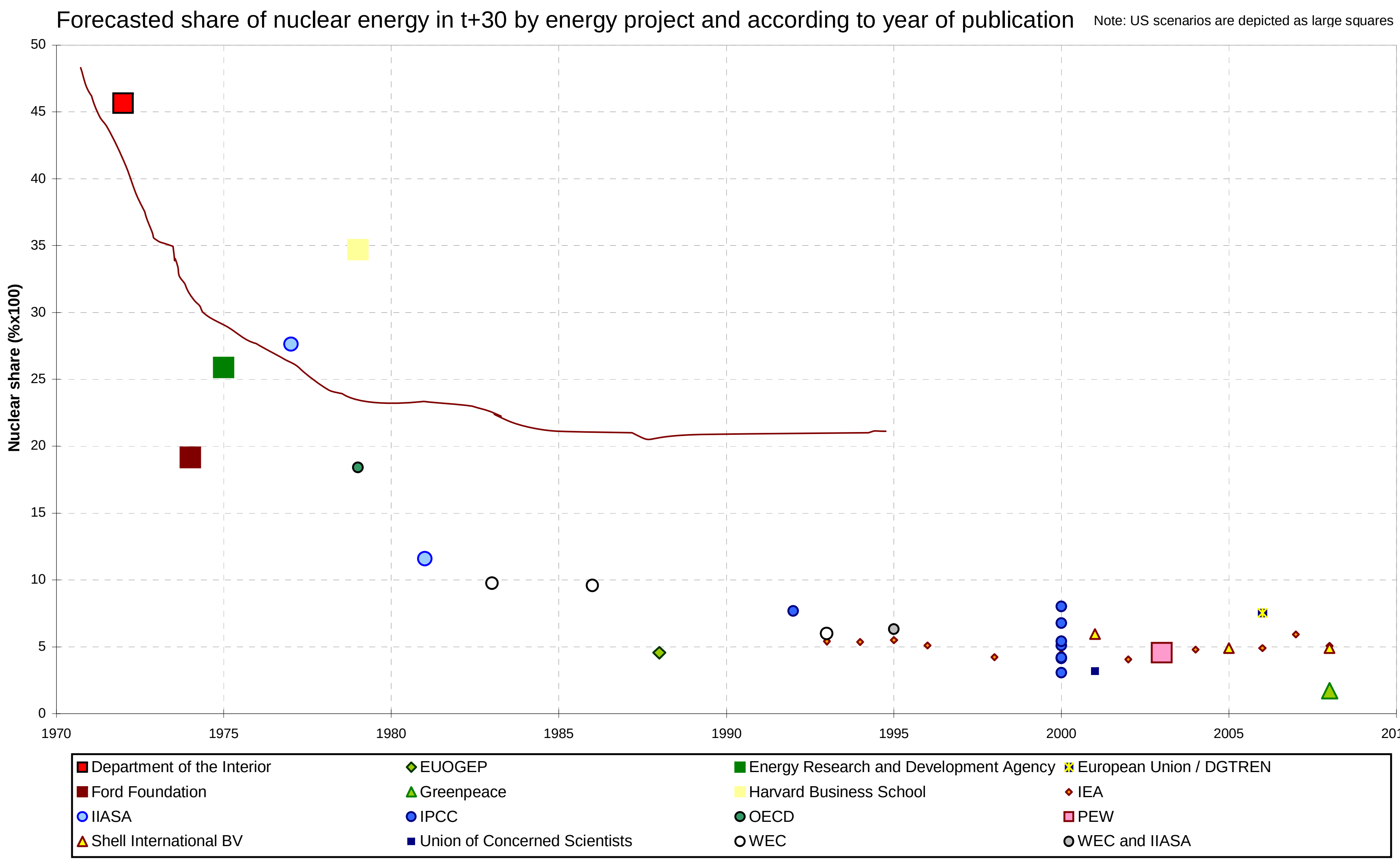
This pessimism cannot obviously be extrapolated for the future but the above analysis is a reminder of the false impression of the ease of substituting for fossil fuels, an impression that emerges in long-run energy forecasting. That a large scale option can be broken by a sudden rise of public concern is not unique to nuclear energy (as we now see for carbon sequestration and for the impacts of wind energy on landscapes); in the same way efforts on new and renewable energies can be discouraged by periods of low energy prices and be made unsuccessful by too large a spectrum of options. Our concluding message is that the optimism necessary to mobilize efforts to develop low carbon energy supply should not be used to divert attention away from efforts to modify the dynamics of the energy demand nor from the enforcement of policies necessary to create stable carbon prices and encourage the taking of investment risks.

Figure 13



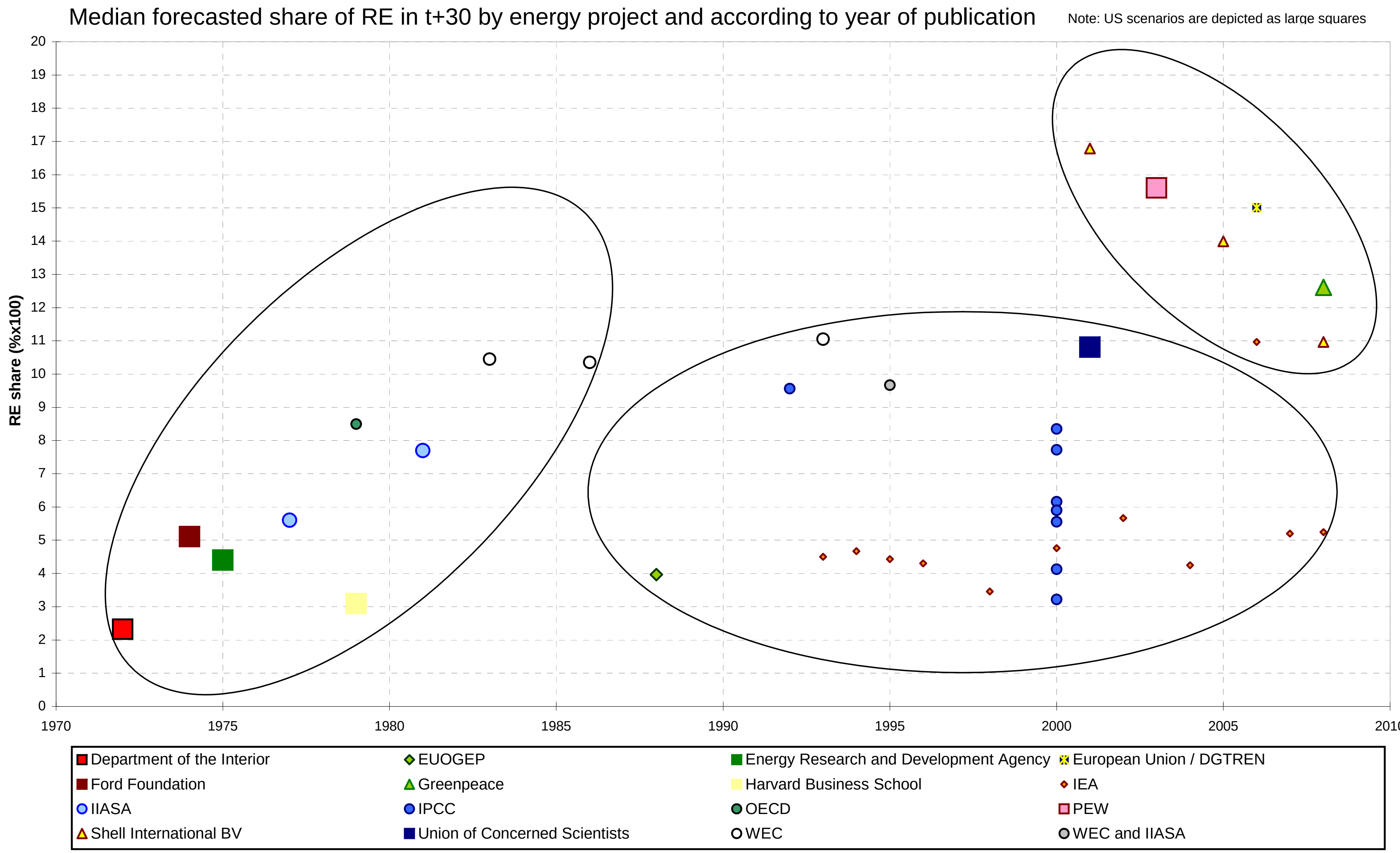
Forecasted share of fossil energy in t+30 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
Fossil energy share (%x100)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

Figure 14



Forecasted share of nuclear energy in t+30 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
Nuclear share (%x100)
50
45
40
35
30
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

Figure 15



Median forecasted share of RE in t+30 by energy project and according to year of publication
Note: US scenarios are depicted as large squares
RE share (%x100)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
1970
1975
1980
1985
1990
1995
2000
2005
2010
Department of the Interior
EUOGEP
Energy Research and Development Agency
European Union / DGTREN
Ford Foundation
Greenpeace
Harvard Business School
IEA
IIASA
IPCC
OECD
PEW
Shell International BV
Union of Concerned Scientists
WEC
WEC and IIASA

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Annex

Table 1 summarizes the energy forecasting projects included in this report. The table reports the project name, the supporting institution, the geographic scope, and respectively, the years of publication, reference, and forecast, and, finally, the number of scenarios in the project.

We define an energy project as a self-contained study realized by a sponsoring institution for a given purpose and published at a given year. Under this definition, the IEA World Energy Outlooks constitute different projects because they are published at different years. The same is true of the IPCC emissions scenarios. One project comes along with a set of scenarios.

Thus we have a total of 32 energy projects with a total of 116 scenarios. The geographic scope is the world for 26 projects, the US for 5, and the EU for 1. Excluding the IPCC scenarios, there are 30 projects and 74 scenarios. The years of publication range from 1972 to 2008, thus spanning 36 years of energy forecasting.

Table 2 summarizes the complete dataset that is displayed in the graphics.

Table 1: Summary of Energy Projects Incorporated

Project Name	Institution	Scope	Year of Publication	Year of Reference	Year of forecast	Number of scenarios
Unites States Energy though the Year 2000	Department of the Interior	US	1972	1972	2000	1
Energy Policy Project	Ford Foundation	US	1974	1973	2000	6
National Energy R&D plan	Energy Research and Development Agency	US	1975	1972	2000	6
Workshop on Alternative Energy Strategies	IIASA	World	1977	1975	2000	4
Facing the Future	OECD	World	1979	1975	2000	1
Energy Future in the USA	Harvard Business School	US	1979	1979	2000	1
Energy in a Finite World	IIASA	World	1981	1975	2030	4
World Energy Council 1983	WEC	World	1983	1978	2020	2
World Energy Council 1986	WEC	World	1986	1980	2020	2
Energy for a Sustainable World	EUOGEP	World	1988	1980	2020	2
World Energy Council 1993	WEC	World	1993	1990	2020	4
WEC-IIASA95	WEC and IIASA	World	1995	1990	2020	6
Shell Energy Needs and Possibilities	Shell International BV	World	2001	2000	2025	2
Shell Energy 2008	Shell International BV	World	2008	2000	2030	2
Shell Global Scenarios 2025	Shell International BV	World	2005	2005	2025	3
US Energy Scenarios for the 21st Century	PEW	US	2003	2000	2035	6
Greenpeace Energy Revolution	Greenpeace	World	2008	2005	2050	2
Union of Concerned Scientists	Clean Energy Blueprint Scenario	US	2001	2000	2020	2
European Energy and Transports	European Union / DGTREN	EU	2006	2000	2030	3
World Energy Outlook 1993	IEA	World	1993	1990	2010	1
World Energy Outlook 1994	IEA	World	1994	1991	2010	1
World Energy Outlook 1995	IEA	World	1995	1992	2010	2
World Energy Outlook 1996	IEA	World	1996	1993	2010	2
World Energy Outlook 1998	IEA	World	1998	1995	2020	1
World Energy Outlook 2000	IEA	World	2000	1997	2020	1
World Energy Outlook 2002	IEA	World	2002	2000	2030	1
World Energy Outlook 2004	IEA	World	2004	2002	2030	1
World Energy Outlook 2006	IEA	World	2006	2004	2030	2
World Energy Outlook 2007	IEA	World	2007	2005	2030	2
World Energy Outlook 2008	IEA	World	2008	2006	2030	1
IS92	IPCC	World	1992	1990	2025	6
IPCC SRES	IPCC	World	2000	1990	2030	36

Table 2: Project Details and Computed Forecasts for 2010 and t+30

Project Name (a)	Institution	Scope	Publication year	Reference year	Forecast year (b)	Number of scenarios	Primary energy shares in 2010 (c)			Primary energy shares in t+30 (c)		
							Nuclear	RE	Fossils	Nuclear	RE	Fossils
Unites States Energy though the Year 2000	Department of the Interior	US	1972	1972	2000	1	42.0	2.5	55.3	45.7	2.3	51.8
Energy Policy Project	Ford Foundation	US	1974	1973	2000	6	31.0	5.0	64.0	19.2	5.1	75.7
National Energy R&D plan	Energy Rsrch & Dev Agency	US	1975	1972	2000	6	30.7	4.1	66.3	25.9	4.4	70.9
Workshop on Alternative Energy Strategies	IIASA	World	1977	1975	2000	4	39.2	4.4	55.5	27.6	5.6	66.8
Facing the Future	OECD	World	1979	1975	2000	1	25.9	8.8	65.4	18.4	8.5	73.1
Energy Future in the USA	Harvard Business School	US	1979	1979	2000	1	36.5	3.0	60.5	34.7	3.1	56.0
Energy in a Finite World	IIASA	World	1981	1975	2030	4	13.4	8.1	78.7	11.6	7.7	80.7
World Energy Council 1983	WEC	World	1983	1978	2020	2	10.2	10.9	71.3	9.8	10.5	71.8
World Energy Council 1986	WEC	World	1986	1980	2020	2	9.6	10.4	72.6	9.6	10.4	72.6
Energy for a Sustainable World	EUOGEP	World	1988	1980	2020	2	4.6	4.4	55.5	4.6	4.0	75.7
IS92	IPCC	World	1992	1990	2025	6	6.7	8.3	84.8	7.7	9.6	80.4
World Energy Council 1993	WEC	World	1993	1990	2020	4	5.7	9.5	75.2	6.0	11.1	73.8
World Energy Outlook 1993	IEA	World	1993	1990	2010	1	6.0	4.1	89.9	5.4	4.5	90.1
World Energy Outlook 1994	IEA	World	1994	1991	2010	1	6.1	4.1	89.8	5.4	4.7	90.0
WEC-IIASA95	WEC and IIASA	World	1995	1990	2020	6	6.1	9.5	75.4	6.3	9.7	74.8
World Energy Outlook 1995	IEA	World	1995	1992	2010	2	6.4	3.8	89.8	5.5	4.4	90.1
World Energy Outlook 1996	IEA	World	1996	1993	2010	2	6.0	3.8	90.3	5.1	4.3	90.6
World Energy Outlook 1998	IEA	World	1998	1995	2020	1	5.3	3.0	82.9	4.2	3.5	84.5
World Energy Outlook 2000	IEA	World	2000	1997	2020	1	5.5	4.5	80.3	4.5	4.8	80.2
IPCC SRES (d)	IPCC	World	2000	1990	2030	36	3.3	4.5	85.1	5.1	5.6	81.1
SRES-AIM	IPCC	World	2000	1990	2030	7	2.6	2.5	87.8	4.1	3.2	83.7
SRES-ASF	IPCC	World	2000	1990	2030	4	2.6	3.3	93.8	3.0	4.1	88.1
SRES-IMAGE	IPCC	World	2000	1990	2030	2	4.3	14.1	79.5	6.8	8.3	77.4
SRES-MARIA	IPCC	World	2000	1990	2030	4	2.2	4.7	82.4	4.2	7.7	76.1
SRES-MESSAGE	IPCC	World	2000	1990	2030	8	4.6	5.1	84.7	5.4	6.2	81.1
SRES-MINICAM	IPCC	World	2000	1990	2030	11	6.5	5.7	84.3	8.0	5.9	80.6
Shell Energy Needs and Possibilities	Shell International BV	World	2001	2000	2025	2	7.1	8.4	84.5	5.9	16.8	79.2
Clean Energy Blueprint Scenario	Union of Concerned Scientists	US	2001	2000	2020	2	7.0	8.8	83.8	3.2	10.8	85.9
World Energy Outlook 2002	IEA	World	2002	2000	2030	1	6.0	4.8	77.4	4.0	5.7	78.2
US Energy Scenarios for the 21st Century	PEW	US	2003	2000	2035	6	7.2	8.1	84.3	4.5	15.6	79.8
World Energy Outlook 2004	IEA	World	2004	2002	2030	1	6.4	3.1	80.2	4.8	4.2	81.5
Shell Global Scenarios 2025	Shell International BV	World	2005	2005	2025	3	6.2	8.7	85.1	4.9	14.0	81.1
European Energy and Transports	European Union / DGTREN	EU	2006	2000	2030	3	14.1	7.8	77.8	7.5	15.0	77.7
World Energy Outlook 2006	IEA	World	2006	2004	2030	2	5.8	3.9	80.9	4.9	11.0	73.3
World Energy Outlook 2007	IEA	World	2007	2005	2030	2	6.5	2.7	80.2	5.9	5.2	78.6
Shell Energy 2008	Shell International BV	World	2008	2000	2030	2	5.8	3.9	80.9	4.9	11.0	73.3
Greenpeace Energy Revolution	Greenpeace	World	2008	2005	2050	2	5.7	3.1	81.1	1.7	12.6	71.6
World Energy Outlook 2008	IEA	World	2008	2006	2030	1	6.2	3.0	80.6	5.1	5.2	80.0

Notes:

(a) the energy projects are sorted by increasing date of publication, as in the figures of the main text;

(b) the year of forecast reported here may differ from the original one, especially for the IPCC scenarios; as said in the methodology section, we retained forecasts not beyond 2050;

(c) the reported shares are the median shares across all the scenarios of each energy project;

(d) the IPCC SRES scenarios are reported according to the median projections of each the six model runs; we also included the whole of IPCC SRES scenarios as an extra data point.