Center for RESOURCE SOLUTIONS

Review of Renewable Energy in Global Scenarios

for the International Energy Agency IEA Implementing Agreement on Renewable Energy Technology Deployment June 2007

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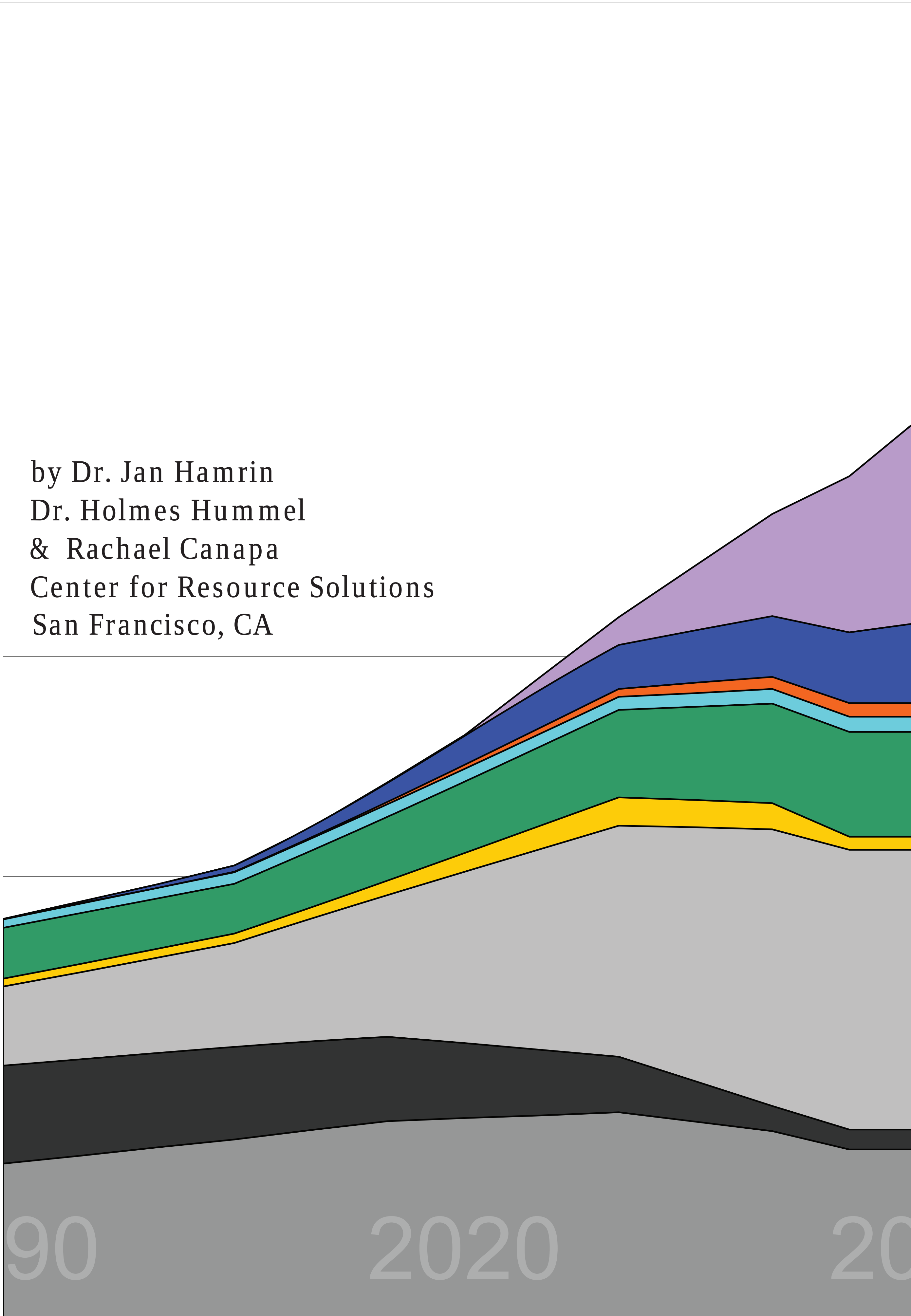

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REVIEW OF THE ROLE OF RENEWABLE ENERGY IN GLOBAL ENERGY SCENARIOS

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For

**The International Energy Agency
Implementing Agreement on Renewable Energy Technology Deployment**

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EXECUTIVE SUMMARY
REVIEW OF THE ROLE OF RENEWABLE ENERGY IN GLOBAL ENERGY SCENARIOS

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What energy future we ultimately experience is the result of choice; it is not fate. Policy makers, investors and consumers do have choices, and every indication in the headlines today is that their decisions are not tracking to the trends of the past. Energy scenarios can help these decision-makers evaluate the available options and the potential implications of their choices. However, to be useful scenarios are needed that provide a broad range of energy options and include explicit data with regard to the assumptions that went into the analysis.

Scenarios are analytical tools that describe our future energy supply. The purpose of this report is to: (1) explain why certain global energy scenarios contain larger shares of renewable energy than others; (2) identify key assumptions; and (3) recommend appropriate settings for assumptions critical to the role of renewable energy that might be used in future global energy scenarios.

As the basis for the discussion of the role of renewable energy technologies in scenarios, the authors undertook a comparison of a group of primarily global energy scenarios. The approach included a comparison of:

- The goals of the scenarios
- The role of renewable energy in terms of shares and growth rates
- The methods used to derive the scenarios
- The key assumptions used in the scenarios
- How costs, benefits and potentials of renewable energy technologies were considered; and
- Major common grounds and differences

The analysis included eleven reports and 35 scenarios but because of constraints on time, resources, and data availability, we were not able to go into depth on all of them. The reports that were analyzed included:

- IEA World Energy Outlook 2006 (WEO 06)
- IEA Energy Technology Perspectives, 2006 (ETP)
- Intergovernmental Panel on Climate Change Fourth Assessment Report Summary for Policy Makers Working Group 1, 2000 (IPCC)[1]

[1] Although these three scenarios are most recently featured in the IPCC's Fourth Assessment Report (2007) because they were selected for use by Working Group 1, the underlying energy scenarios were originally published in the IPCC's Special Report on Emissions Scenarios (2000).

- World Energy Technology Outlook, 2006 (WETO H_2)
- World Energy Council Global Energy Scenarios, 1998 (WEC GES 2050)
- German Advisory Council on Global Change – Climate Protection Strategies for the 21st Century: Kyoto and Beyond, 2003 (WBGU)
- European Renewable Energy Council/Greenpeace Energy [r]evolution, 2007 (EREC/Greenpeace)
- European Energy and Transport Scenarios on Energy Efficiency and Renewables, 2006 (EET/Eff & RE – European scenarios)
- American Solar Energy Society – Tackling Climate Change in the U.S., 2007 (ASES – U.S. Scenario)

For a variety of reasons we reviewed but did not analyze the two reports with detailed "storyline" scenarios:

- Shell Global Scenarios to 2025, 2005 (Shell)
- Pew Center U.S. Energy Scenarios for the 21st Century, 2003 (PEW)

The report discusses the types of scenarios and their uses, the types of models used, and how various technologies are characterized in the different scenario sets. These technologies are shown in the table below, according to the data available.

Table A: Technology Types Included in Scenario Sets

	Type of Technology	IEA WEO 2006	IEA ETP	IPCC	WETO H2	WEC GES to 2050	EREC/ Green-peace	EET Eff and RE	ASES	WBGU
Renewable Electricity Sources	Hydropower	X	X		X	X	X	X		X
	Biomass	X	X	X	X	X	X	X	X	X
	Geothermal	X	X		X		X	X	X	X
	Solar	X	X		X	X	X	X	X	X
	Solar Photovoltaics	X	X		X		X	X	X	X
	Concentrating Solar Power	X	X		X		X		X	X
	Wind Energy	X	X		X		X	X	X	X
	Ocean Energy	X	X				X	X		
	Other Renewables			X		X				
	Energy Efficiency	X	X	X	X	X	X	X	X	X
	Solar Heating and Cooling		X				X	X		X
	Biofuels	X	X		X		X	X	X	
	Nuclear	X	X	X	X	X		X		X
	Hydrogen	X	X		X			X	X	X
	Carbon Sequestration	X	X	X	X				X	X

The report characterizes the role of renewable energy for each reviewed scenario individually, and these results and key driver metric "dashboard" diagrams are presented in Appendix II. The report also includes a series of comparisons between the scenario results using different indicators, one of which is the share of renewables in the primary energy portfolio. Among the baseline reference scenarios that best reflect "business as usual", there is little variation in the expectation for the role of renewables in the future, around 11-15% of primary energy production by 2050. Large differences are seen between scenarios that assume specific policy interventions or technological innovations that change the course of the future based on one of the "business as usual" reference cases. For these intervention cases, the EREC/Greenpeace and WBGU B1-400 scenarios are the most ambitious, reaching nearly 50% of the primary energy profile by 2050. Other intervention cases ranged from 19.0 to 42.5% for the share of renewables in primary energy by 2050. Exploratory reference cases involve implicit assumptions about how the future could be very different from the past and are not the result of a single policy. These scenarios showed a variation between 11.6% and 39.4% renewable energy share of primary energy by 2050.

The results for invention cases and exploratory reference cases vary widely for two reasons: (1) the types and combinations of interventions across these scenarios are quite heterogeneous and (2) the modeling tools that characterize the effects of those interventions also vary in nature. Furthermore, the range of renewable technologies characterized for each scenario is different for each scenario, as shown in the Technology Matrix Table above.

Another indicator investigated was the portion of electricity expected to be generated from renewable energy sources for each of the scenarios for which electric power sector data were disclosed. The EREC/Greenpeace [r]evolution scenario is strikingly optimistic, reaching 70% by 2050, while all the other scenarios cluster in the 25-35% range. The lowest two scenarios for share of renewables in electricity generation are the IEA World Energy Outlook Baseline Scenarios that anticipate no change in policy context.

Because global energy scenario models are structured to seek a combination of cost-effective energy supplies to meet a given demand, the cost characteristics assigned to each renewable energy technology are critical determinants. However, the analysis prepared for this report was challenged by lack of data disclosure and transparency about cost assumptions. Only four of the scenario studies reviewed for this report published or provided the input cost assumptions for renewable energy technologies: IEA Energy Technology Perspectives (Map scenario), IEA World Energy Outlook 2006, EREC/Greenpeace Energy [r]evolution, and ASES.

Renewable energy and energy efficiency are categories of mitigation measures that appear in nearly every climate stabilization scenario, and many energy experts would agree that carbon reduction targets are expected in the future. However, among the scenarios selected for review, few explore the impact of explicit climate policies to limit greenhouse gas emissions. Though only four of the future energy scenarios considered the effect of imposing emissions constraints on the energy sector, most of the scenarios published data for carbon emissions from the energy sector, which provide a key basis for comparison among scenarios via a dashboard of key emissions drivers.

Having completed the analysis, the authors suggest seven overarching recommendations to modeling teams constructing future global energy scenarios:

1. Provide **data transparency** for scenario inputs and outputs, including cost and performance assumptions.
2. Clearly articulate the **scenario frame**, describing the question the scenario seeks to answer.
3. Expand the **range of renewable energy technologies** included to explore the range of options available for reducing carbon emissions from the energy sector.
4. Provide detailed **characterization of renewable energy technologies**, similar to the ASES report.
5. Evaluate the impact of policy interventions for the **role of efficiency** by referencing metrics for final energy intensity of economic activity and energy supply loss factor.
6. Clearly **describe model features** and the relationships between the principle factors.
7. Consider the impact of **carbon constraints and climate policies**.

The scenarios reviewed do support some valuable observations for the field of scenario analysts and an audience of scenario users interested in the role of renewable energy. First, the reference scenarios reviewed in this report tend to suggest a relatively modest role for renewable energy technologies four decades in the future. Second, even after applying a number of imagined policy interventions or technology innovations, most of the intervention scenarios indicated 80% of the primary energy portfolio in 2050 would still come from non-renewable sources. The IEA ETP study and the EREC/Greenpeace [r]evolution scenario are notable exceptions, indicating much more aggressive deployment of renewable energy technologies. The two general observations above lead to two different types of interpretations:

1. The models generating the scenarios reviewed accurately describe the energy-economic system as well as the intervention policies. Therefore, the relatively minor role of renewable energy (and the persistent large-scale use of fossil fuels) indicates that the policies presently proposed are inadequate to the task of meeting the climate challenges – <u>something far more bold is required.</u>

Or,

2. The relatively minor potential for renewable energy technologies in the results of an intervention scenario suggests that its modeling assumptions do not accurately capture the changing market conditions, the rate of technological innovation, and the stimulus of multiple policy interventions.

The published reports representing each of the scenarios reviewed did not include a sufficient level of input data or technology characterization to draw either conclusion for each individual scenario. However, this report frames the considerations that would apply to such an evaluation for all of them, a product that is intended to contribute to the development and evaluation of future global energy scenarios.

Those scenarios that do feature the most significant contribution from renewable energy technologies draw heavily on energy efficiency improvements as well. Among the renewable energy sources, biomass was routinely reported to dominate the other options. However, few scenarios include a full range of renewable energy and efficiency options. Exploring the full potential of these options can offer a decision-maker striving to achieve energy security, sustainable development, and climate stabilization a broader range of energy opportunities, many of which are available today. Whereas some technologies only respond to explicit climate policies (e.g. carbon sequestration or solar-sourced hydrogen), the combination of renewable energy and energy efficient technologies supports all three of those overarching objectives for the 21^{st} century.

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REVIEW OF THE ROLE OF RENEWABLE ENERGY IN GLOBAL ENERGY SCENARIOS

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INTRODUCTION

The purpose of this report is to: (1) explain why certain scenarios contain larger shares of renewable energy than others; (2) identify key assumptions; and (3) recommend appropriate settings for assumptions critical to the role of renewable energy that might be used in future global scenarios.

As the basis for the discussion of the role of renewable energy technologies in scenarios, the authors undertook a comparison of a group of primarily global energy scenarios. The approach included a comparison of:

- The goals of the scenarios
- The role of renewable energy in terms of shares and growth rates
- The methods used to derive the scenarios
- The key assumptions used in the scenarios
- How costs, benefits and potentials of renewable energy technologies were considered; and
- Major common grounds and differences

The analysis included eleven reports and 35 scenarios but because of constraints on time, resources, and data availability, we were not able to go into depth on all of them. The reports that were analyzed included:

- IEA World Energy Outlook 2006 (WEO 06)
    - Base case
    - Alternative Policy Scenario (APS)
    - Beyond Alternative Policy Scenario (BAPS)
- IEA Energy Technology Perspectives, 2006 (ETP)
    - ACT MAP
    - Low Renewable Energy (Low RE)
    - Low Nuclear
    - No Carbon Capture and Sequestration (No CCS)
    - Low Energy Efficiency (Low EE)
    - Tech Plus

- Intergovernmental Panel on Climate Change Fourth Assessment Report Summary for Policy Makers Working Group 1, 2000 (IPCC)[1]
    - A1B
    - A2
    - B1
- World Energy Technology Outlook, 2006 (WETO H_2)
    - Reference
    - Carbon Constrained
    - H_2 Development
- World Energy Council Global Energy Scenarios, 1998 (WEC GES 2050)
    - Case A1 and A3
    - Case B
    - Case C1 and C2
- German Advisory Council on Global Change – Climate Protection Strategies for the 21st Century: Kyoto and Beyond, 2003 (WBGU)
    - A1T – 450ppm
    - B1 – 400ppm
- European Renewable Energy Council/Greenpeace Energy [r]evolution, 2007 (EREC/Greenpeace)
    - IEA World Energy Outlook 2004 (WEO 04)
    - [r]evolution
- European Energy and Transport Scenarios on Energy Efficiency and Renewables, 2006 (EET/Eff & RE – European scenarios)
    - Baseline
    - High Efficiency
    - High Renewables 12% in 2010
    - Combined Efficiency & Renewable Energy
    - Combined 12% Efficiency
- American Solar Energy Society – Tackling Climate Change in the U.S., 2007 (ASES – U.S. Scenario)
    - EIA Annual Energy Outlook 2006
    - 60 to 80% Reduction

For a variety of reasons we reviewed but did not analyze the two reports with detailed "storyline" scenarios: [2]

- Shell Global Scenarios to 2025, 2005 (Shell)
    - Low Trust

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[1] Although these three scenarios are most recently featured in the IPCC's Fourth Assessment Report (2007) because they were selected for use by Working Group 1, the underlying energy scenarios were originally published in the IPCC's Special Report on Emissions Scenarios (2000).

[2] Data for the Shell scenarios were not available, and time and resource constraints prevented us from evaluating in greater detail the Pew Center scenarios.

- Open Doors
- Flags

- Pew Center U.S. Energy Scenarios for the 21st Century, 2003 (PEW)
    - Awash in Oil & Gas
    - Technology Triumphs
    - Turbulent World

The following figures highlight some of the key results of our analysis with regards to the amount of renewables contained in various scenarios. Only those scenarios for which sufficient data were available appear in each figure.

Shares of Renewable Energy in Reviewed Scenarios

The role of renewable energy in a global energy scenario can be characterized using several different indicators, one of which is share of the energy portfolio. This report characterizes the role of renewable energy for each reviewed scenario individually in Appendix II. The following set of figures present a series of comparisons between the scenario results using three different indicators: renewable energy as a share of primary energy, renewable energy as a share of the electric power sector, and intermittent renewable energy as a share of the electric power sector.

Figures 1A, 1B, and 1C separate the entire batch of scenarios by their scenario frame, a distinction of purpose that is described in the following section on types of scenarios (see page 8). Figure 1A illustrates the share of renewable energy as a portion of primary energy for reference cases that extend recent trends into the future (e.g. outlook scenarios). Among the four different baselines that best reflect "business as usual", there is little variation in the expectation for the role of renewables in the future. While the aggregate energy production from renewable energy technologies does grow over the fifty-year time horizon, it increases at nearly the same rate as the total growth in global energy use, which leaves the renewable energy portion of primary energy at a fairly low level.

Figure 1B illustrates renewable energy as a share of primary energy production for only those scenarios that assume specific policy interventions or technological innovations that change the course of the future based on one of the "business as usual" reference cases, which are also plotted.[3] The results vary widely for two reasons: (1) the types and combinations of interventions across these scenarios are quite heterogeneous and (2) the modeling tools that characterize the effects of those interventions also vary in nature. Furthermore, the range of renewable technologies characterized for each scenario is different for each scenario. Overall, the EREC/Greenpeace and WBGU B1-400 are the most ambitious, reaching nearly 50% of the primary energy profile. After the WBGU scenarios, the IEA ETP Tech Plus scenario reaches 30% followed by several variations

[3] The WBGU A1T and B1 scenarios are actually exploratory baselines (Figure 1C). However, they are also included in Figure 1B because their characteristics indicate implicitly assume interventions in the policy context and characteristics of technologies available today – and they also provide some context to the A1T-450 and B1-400 intervention cases in Figure 1B.

on the Map scenario of that same study. The WETO-H2 study yields a pair of scenarios that reach 20%.

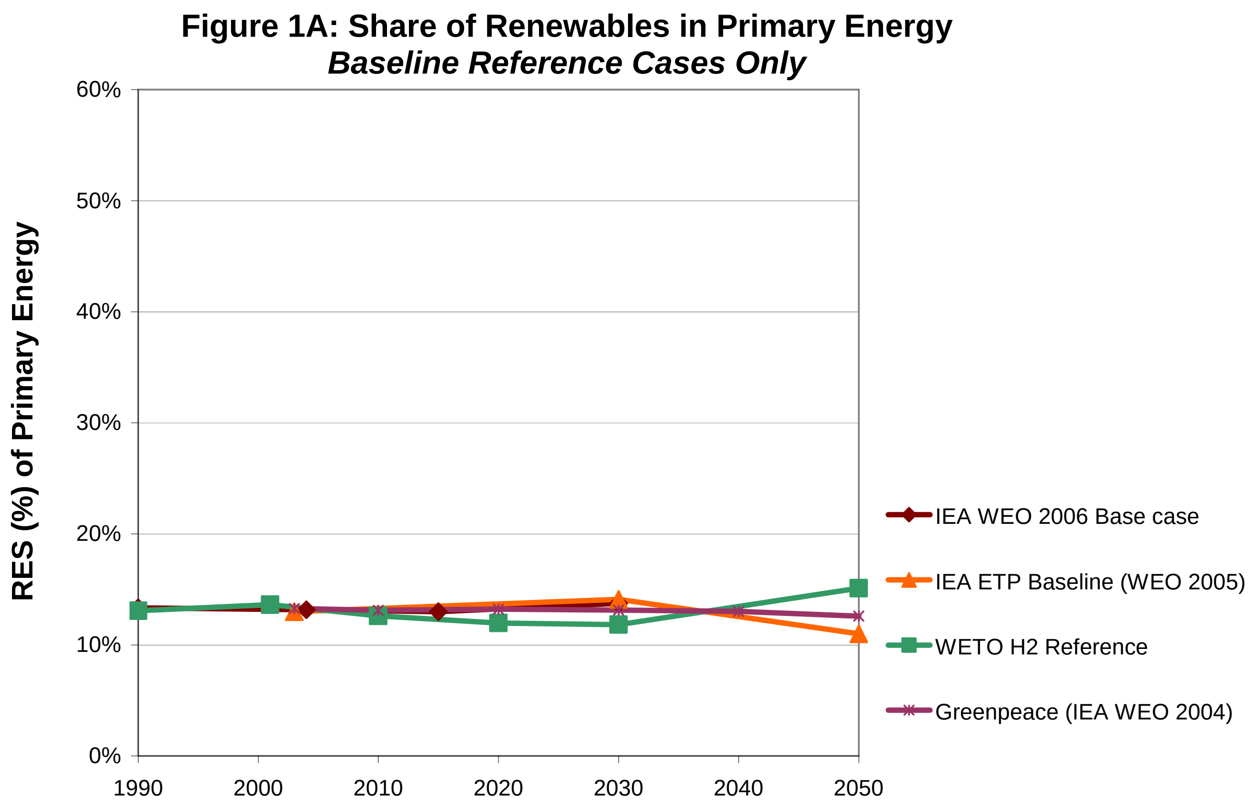

Figure 1B: Share of Renewables in Primary Energy
Intervention Cases, with Reference Cases

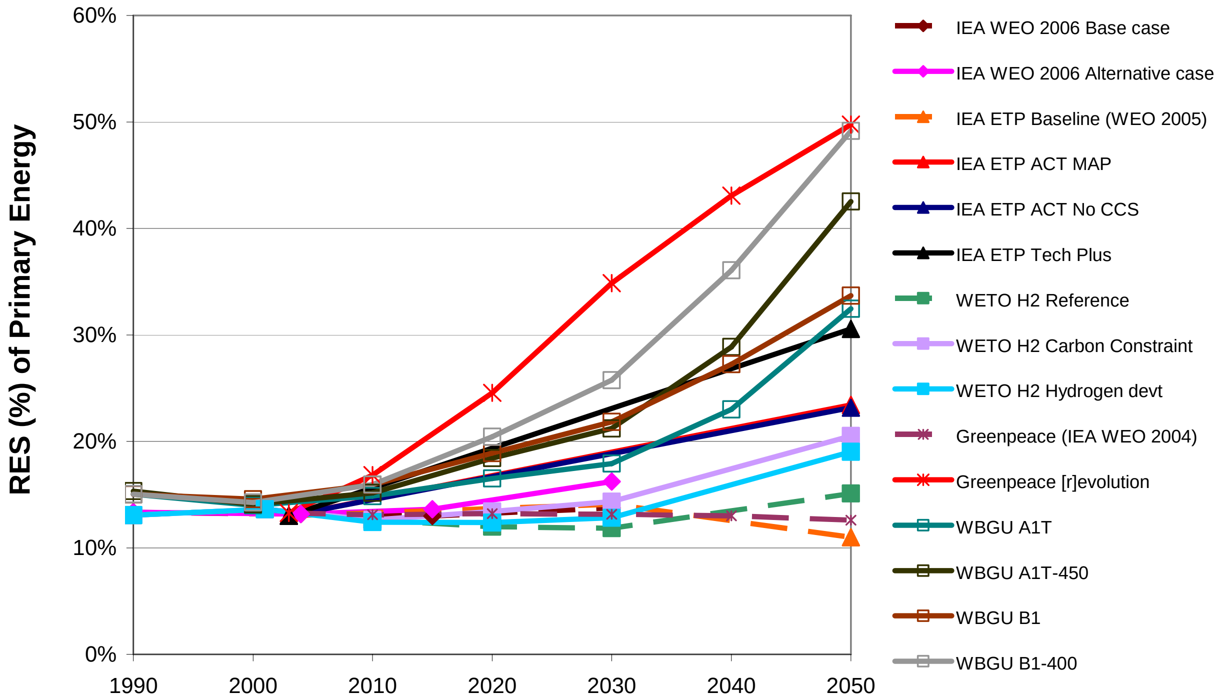

Figure 1C: Share of Renewables in Primary Energy
Exploratory Reference Cases Only

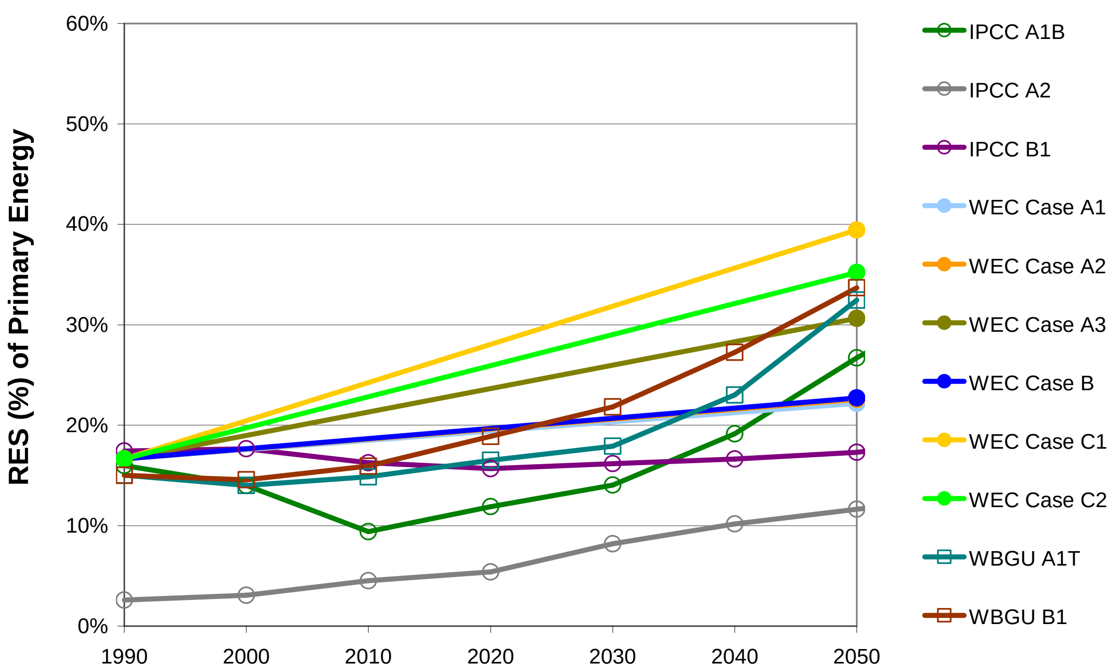

Figure 1C illustrates a collection of scenarios categorized as exploratory reference cases, which involve implicit assumptions about how the future could be very different from the past.[4] Unlike intervention scenarios that examine the impact of a specific policy on a predefined future, the exploratory reference cases explore uncertainties about key drivers such as population growth, trade patterns, and rates of technological innovation. Though these exploratory reference cases do diverge from business as usual, they are not the result of a single policy intervention. (For more discussion of these scenario types, see page 8). The WEC scenarios are the oldest among all the scenarios reviewed in this study, and in many ways, they formed a basis for scenarios subsequently constructed for the IPCC in the Special Report on Emissions Scenarios. All of the other scenarios in Figure 1C were generated for use in the investigation of potential impacts from climate change and opportunities for mitigation. As in Figure 1B, the role of renewable energy varies widely, primarily due to heterogeneous assumptions about the future as well as the diversity of modeling tools used to represent those futures.

An important finding of the analysis of individual scenarios in Appendix II is that biomass by far the largest source of renewable energy among all types characterized, and in many scenarios, it is also indicated to have the highest rate of growth in the future. Biomass includes a variety of plants that can be used for production of liquid fuels, heat, or electricity. Nearly all of the other renewable energy technologies, however, are limited to the electric power sector.

Figure 2 shows the portion of electricity expected to be generated from renewable energy sources for each of the scenarios for which electric power sector data were disclosed. The EREC/Greenpeace [r]evolution is strikingly optimistic, reaching 70% by 2050, while all the other scenarios cluster in the 25-35% range. The lowest two scenarios in the figure are IEA World Energy Outlooks that anticipate no change in policy context.

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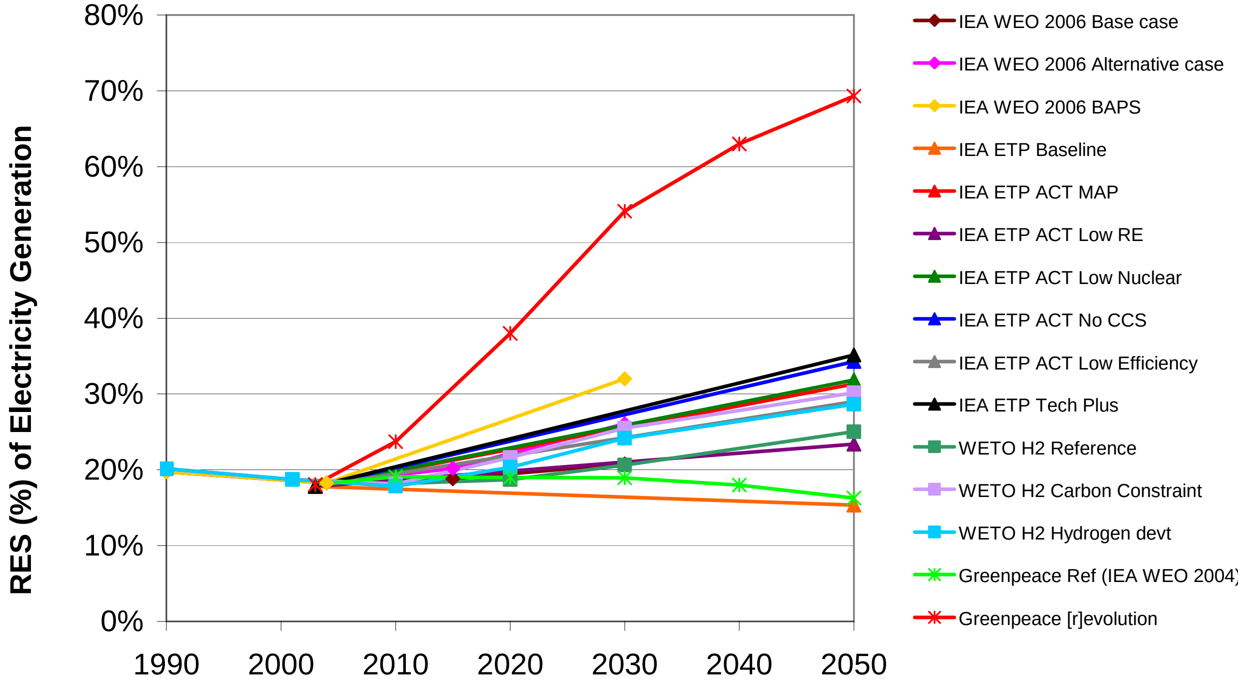
[4] Descriptions of all of these different futures are included in the individual scenario profiles in Appendix II.

Figure 2: Share of Renewables in Electricity Generation



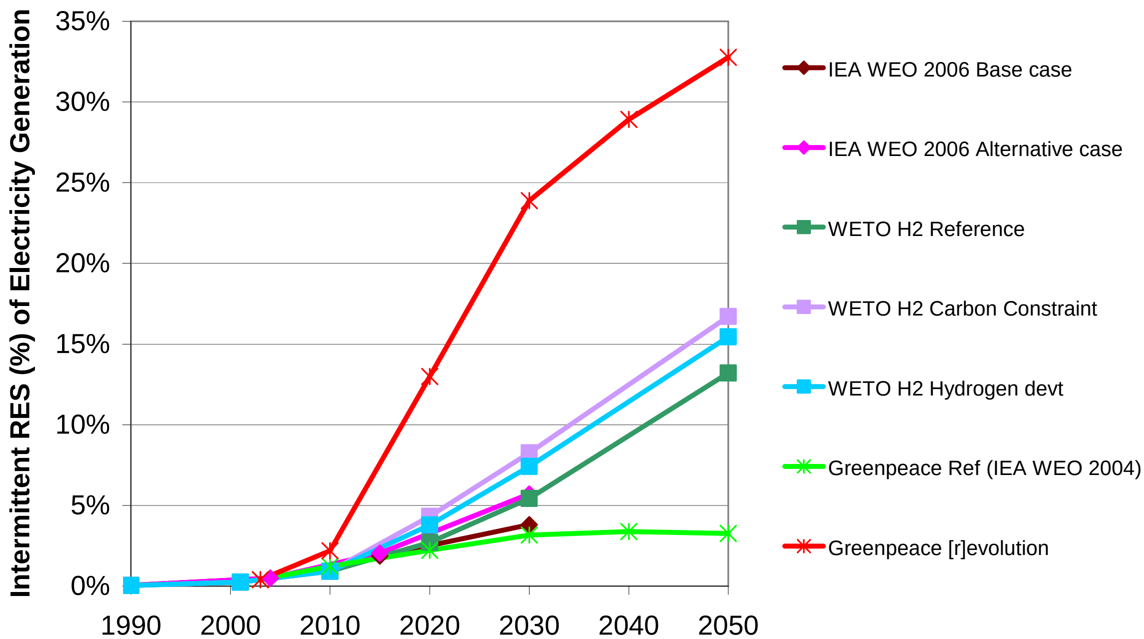
The primary concern with the role of renewable energy in the electric power sector relates to the degree to which it can be integrated into the present grid system of dispatchable power plants. In the electric power sector, biomass is a fuel for thermal power plants that can be dispatched similarly to fossil fuel plants. However, solar, wind, and tidal energy have intermittent, or fluctuating production based on the availability of the primary resource. As a result, these sources of electricity cannot be dispatched by a grid operator. Therefore, as the portion of the power provided to the grid from intermittent sources rises, so does concern about grid stability. At the moment, there is not a known absolute technological constraint on the amount of intermittent renewables allowed while maintaining grid stability. With electrical energy storage capabilities, this value could theoretically be 100%. Practically, the limits on incorporating intermittent renewables are twofold: (1) costs and (2) the capability to change the responsiveness and flexibility of existing generation and distribution systems. Both of these limits are region-specific. Intermittency integration costs become a limiting factor only after penetration rates significantly increase. For example, for California's goal of achieving a 33% renewable energy target by 2020, wind integration costs are expected to rise from $0/MWh today to $2/MWh for capacity added in 2011 and to $5/MWh in 2020[5].

This final summary, Figure 3, indicates the share of intermittent renewables contained in the scenarios that had sufficient data to make this comparison. As in the previous tables, the Greenpeace [r]evolution scenario has the largest proportion of intermittent renewables, 42 percent. Second and third are the WETO H_2 Carbon Constraint Case and

5 Hamrin et al, 2005 – By 2020, wind would comprise approximately 16.5 percent of the supply mix.

H_2 Development Case at 14 and 12 percents respectively. With the exception of the Greenpeace [r]evolution scenario, none of the global scenarios that were analyzed come close to challenging the limits on (1) available resource; or (2) grid stability.[6]

Figure 3: Share of Intermittent Renewables in Electricity Generation



The remainder of this paper focuses on different forms of inquiry for scenario analysis as well as methodologies and assumptions that influence scenario results.

TYPES OF SCENARIOS

What are scenarios? Scenarios are an analytic technique for exploring uncertainty by asking and answering "if … then" questions to support risk management decisions. Scenarios are intended to be internally consistent storylines about possible futures. Each global energy scenario is an abstraction of a possible future described by the combination of numerous input variables including population projections, economic prospects, changes in energy efficiency, shifts between the various fuels, and different rates of technology innovation.

Scenario analysis is a technique -- a method. However, the word "scenario" is also used to describe the product of the analysis. There are several different ways to execute scenario analysis, so not all scenarios are of the same type. The different types of

[6] Though this report examined data primarily at the global level, the portion of grid electricity attributed to intermittent renewable energy technologies in individual regions will vary.

scenarios can be distinguished by the Scenario Frame, or the question each scenario is intended to answer.

Reference scenarios – Any scenario against which another scenario is compared. These scenarios can be framed as, "What if the future has characteristics X, Y, Z?" And if those characteristics reflect present conditions and trends, then the scenario may be used to describe "how the energy system might evolve if we don't do something differently." Such a scenario might also be called a baseline, but not all reference cases project current trends. For instance, the IEA ETP uses a reference case characterized by aggressive technological innovation (ACT MAP) and then compares a series of alternative scenarios that are deprived of one or more of those advances. This type of scenario indicates "how the energy system might evolve in the absence of these technological improvements."

There are three dominant types of reference cases:

- **Outlook scenarios –** "What if the trends of key drivers in the future are similar to the past? Or, what would happen if the policy context in which energy consumers and investors operate were to remain unchanged for 25 years?" An outlook is a type of scenario constructed in a way that extends the trends of the past into the future with policies fixed in their present state. For this reason, outlooks are a lagging indicator in nearly every respect. Because these conditions do not plausibly hold relevance to the future for more than a couple decades, outlooks tend to have a shorter time horizon than other energy scenario products.

The Outlooks tend to reflect a limited role for renewable energy because they essentially project the past into the future. Since most outlook reference cases characterize a very limited range of renewables, the output will have very limited renewable options as well. Because the likelihood that the energy future will be like the energy past is very low, other types of scenario analysis can help illuminate possibilities if the future is expected to be much different from the past.

- **Forecast scenarios –** "What are the most likely conditions of the future?" The difference between an outlook and a forecast is the addition of relative probability. Because policy contexts are always changing, outlooks are rarely considered the most likely future. A forecast, on the other hand, may capture changes anticipated in market rules or technological innovation. There are no forecasts in the scenario set selected for review in this report.

- **Exploratory Reference scenarios –** "What if the trends of key drivers in the future diverge from the past?" Although these reference scenarios may form the basis of experiments that subsequently apply additional policy interventions, these reference cases often include implicit assumptions about policy changes that are already incorporated in the baseline.

Other Scenario Frames – Reference cases are used as a basis of comparison between an imagined future, and the same imagined future with a specific set of changes that would change its course. These limited changes are called interventions.

- **Intervention scenarios –** "What would happen if condition X were imposed on the future described by a reference scenario?" Eleven of the 35 scenarios reviewed for this report are intervention scenarios.

Interventions that are framed as targets require a different type of computational approach that is called *backcasting*.

- **Backcast –** "What energy path would achieve a future condition X?" Backcast scenarios construct a path from conditions specified as a future target back to the present. Of the 11 intervention scenarios reviewed, the WETO H2 Carbon Constrained Scenario, the WBGU stabilization scenarios, the EREC/Greenpeace Energy Revolution scenario, and the IEA/WEO 06 BAPS scenarios are the only four that use a backcast scenario frame.[7]

One other type of scenario, we call an "elaborate storyline scenario," is one sometimes used by businesses or governments for strategic planning purposes. In this type of scenario analysis, much of the time and effort is put into examining the relationships between the key forces that influence future directions. The quantitative results may be less important than the process of developing the scenarios, the qualitative relationships of the drivers, and the various policy or business options for dealing with them.

- **Elaborate storyline scenarios –** Elaborate exploratory type scenarios are based on key internally consistent economic, social and political forces. With these scenarios, insights generated in the process of constructing them are often as or more important than the quantitative results.

The following table indicates the scenarios types used in the reports reviewed:

[7] The Beyond Alternative Policy Scenario uses a "stabilization wedges" frame to add a series of mitigation sources to the solution set of the Alternative Policy Scenario, reducing carbon dioxide emissions until a specific mitigation target is reached. This hybrid approach is qualitatively and logically different than the other three backcast scenarios.

Table 1: Different Types of Scenarios in the Sample

Study	Scenario Type
IEA WEO 2006	Outlook, Intervention (APS) and Backcast (BAPS)
IEA ETP	Outlook, and Intervention
WETO H2	Outlook, Backcast and Intervention
SRES (IPCC)	Exploratory reference
WEC	Exploratory reference
WBGU	Exploratory reference and Backcast
EREC/GP	Outlook, and Backcast
EET RE & EE	Outlook, and Intervention
ASES	Tech. Specific -- Bottom up
SHELL	Storyline
PEW	Storyline

SCENARIO FRAMES

Scenario analysis is designed to explore a wide variety of futures that challenge the comparability of results. Distinguishing between types of scenarios and their context for inquiry is necessary to ensure valid comparisons between scenarios with different frames. A scenario frame summarizes the question the scenario experiment is constructed to answer. The following is a summary of some of the questions addressed by the scenarios reviewed in this sample.

- What if current policies continue?
- What if policies currently under consideration are adopted?
- What if policies under consideration are adopted while maintaining a "balanced" set of technologies?
- What if the energy sector had a carbon constraint of 500 parts per million of carbon dioxide by volume (ppmv CO_2) in 2100?
- What if technological innovation occurred more rapidly than the present trends?
- What are the potential carbon emission reductions from a scenario with maximum feasible implementation of energy efficiency and renewable energy by 2030?

Profiles of the scenario frames for 26 of the scenarios analyzed are included in Appendix II with a description of the profile format in Appendix I.

With a sample set of scenarios that all return different results for renewables, it is tempting to ask, "Which one is correct?" Any scenario with an internally consistent set of relationships and data relevant to a specified scenario frame can be valid, even if none of them come to pass in reality. Therefore, it is more insightful to ask, "Which future energy scenario has a frame that is relevant to the present decisions to be made today?" In order to have policy relevance in their results, many of the scenarios reviewed in this report are framed to explore the impact of specific policy proposals.

The Case for a Carbon Constrained Future

Scenarios charting paths toward climate stabilization typically require a time horizon of a century or more, and the modeling techniques and assumptions used to execute these long-term experiments are typically different than the ones used to answer scenarios framed to explore the near term policy impacts. Nevertheless, scenarios exploring the implications of interim targets or transitions to paths toward stabilization over a few decades can yield important insights for decision makers regarding robust strategies for energy security, sustainable development, and climate stabilization.

Renewable energy and energy efficiency are categories of mitigation measures that appear in nearly every climate stabilization scenario, and many energy experts would agree that carbon reduction targets are expected in the future. However, among the scenarios selected for review, few explore the impact of explicit climate policies to limit greenhouse gas emissions. Though only four of the future energy scenarios considered the effect of imposing emissions constraints on the energy sector, most of the scenarios published data for carbon emissions from the energy sector, which provide a key basis for comparison among scenarios via a dashboard of key emissions drivers (Appendix II).

TYPES OF MODELS

There are two critical dimensions of uncertainty about energy futures: one is the <u>value of the parameters</u> that describe that future (e.g., the cost of a technology, or the rate of economic growth); and the other is the <u>relationship between parameters</u> (e.g., if economic growth is faster, does technological innovation speed up also?). When combined, these types of uncertainty present conditions of *deep uncertainty*. Scenario analysis is a technique that is particularly well-suited for conditions of deep uncertainty, though the quantitative tools used to characterize those uncertainties may construct abstractions of the future that undermine the credibility of the results.

Each scenario study is typically executed in the context of a single model, or a single set of assumptions about the relationships between variables. Scenario analysts then vary the values assigned to key parameters and examine the effect on the results. In some cases there may be tens of thousands of parameters that could be varied, holding the potential for an infinite number of possible results. However, even if two modeling teams select identical values for key parameters, the results may differ due to the second type of uncertainty, which is typically reflected in the logic of the model structure.

The distinction between uncertainty about key values and relations helps explain why two different models working with essentially the same set of historical data and with the same scenario frame can still yield different answers. Scenario experiments conducted by the IPCC Special Report on Emissions Scenarios highlight the potential for such a wide variation in results.[8] The U.S. Energy Information Administration's International Energy Outlook (from the SAGE model) and the International Energy Agency's World Energy Outlook (from the WEM model) yield different results due to a combination of slightly different assumptions about the future (parameter values) and differences in the relationships between those values encoded in the models.

Table 2: Models Represented in the Sample

Model Name	Study	Type
WEM	IEA WEO 2006	Simulation
MARKAL	IEA ETP	General equilibrium
POLES	WETO H2	Simulation; partial equilibrium
PRIMES	EET RE & EE	General equilibrium
MESAP/PlaNet	EREC/GP	Simulation
MESSAGE	WEC	Linear optimization
AIM	SRES (IPCC)	Simulation
ASF	SRES (IPCC)	Engineering-economic
IMAGE 2.2	SRES (IPCC)	Simulation
MESSAGE	WBGU	Linear optimization

One type of model is not actually predisposed to producing results with more renewables than another. The assumptions characterizing technology options available to each of them can be changed to return high or low contributions from renewables. Nevertheless, it is appropriate and necessary to state that differences between models are an important source of differences in results between scenarios generated by different modeling teams, even when they are striving to characterize similar futures such as a business-as-usual baseline reference case.

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[8] Similarly, comparative multi-model studies conducted by the Energy Modeling Forum or the Potsdam Institute provide a basis for investigating the strengths and weaknesses of various modeling approaches. It is not within the scope of this report to investigate and resolve sources of uncertainty between models.

TECHNOLOGIES

Input assumptions about available energy technologies and their characteristics provide essential context for energy scenario results. Scenarios differ not only in the sets of technology options presumed to be available but also the characterization of each technology type. None of the scenario studies reviewed for this report had consistent energy technology categories or definitions, particularly for the class of renewable energy technologies. While there need not be a single taxonomy of energy resources considered in every energy scenario, it is important to stress that the range of options is a crucial determinant in the results. Moreover, what is portrayed in scenarios often influences what decision makers and investors *believe* is the range of possible options available.

Technology Types

The types and characteristics of technologies included in the various scenario sets influence both the outcome of the analysis as well as the interpretation of the results. For example, the share of primary energy from renewables is similar for the IPCC B1 marker scenario and the WETO H2 reference case. However, the IPCC B1 marker scenario reports nuclear power as part of a "Non-Fossil Electric" category that includes solar and wind power while all the other scenarios (including the WETO H2 reference case) handle nuclear as an entirely separate supply source not combined with renewable energy technologies. Because the quantity of nuclear power is not explicitly reported in the final data set for the IPCC B1 marker scenario, the share of renewable energy in the primary energy profile is overstated.

Biomass is another renewable technology category that can result in comparability problems. More recent IEA scenarios include large quantities of "traditional" or non-commercial biomass while some of the other scenarios do not. Traditional biomass is appropriately an important primary energy resource, but without distinction, it can mask the growth of "new" renewables including "modern" biomass if they are bundled together. Moreover, if the reviewer does not know it is there, large quantities of traditional biomass can lead to erroneous conclusions about the role of renewables overall.

Omission of entire technology sets has an even greater effect on the potential for renewable energy use reflected in global energy scenario results. While Ocean Energy may only make a nominal contribution to the energy resource mix in the near future according to data presently available, other new technologies such as solar thermal electric and off-shore wind generation projects are becoming increasingly economic and commercially attractive generation options. Few of the scenarios reviewed for this report give explicit treatment to any of these three technology types, and omitting these technologies for some geographic regions could significantly underestimate the technical and market potential for renewable energy.

Assuming marginal costs of supply increase for any given technology in a single time period, the more cost-effective technology options are available, the lower the cost of reaching a specified level of renewable in the overall energy portfolio. Conversely, a limited role for renewable energy in the output of a scenario can reflect limitations on the types of renewable energy technologies available for input. If technologies are not characterized in the scenario, then it implicitly assumes they don't exist and thus these technologies cannot contribute at all.

In the Transportation Sector, there are direct tradeoffs between infrastructure regimes based on biofuels, hydrogen, or electricity. All three paths require major investments in new infrastructure that are technically different from each other. Moreover, infrastructure investments have historically been path dependent, favoring variations on incumbent technologies. Biofuels has advantages in this respect, making it a dominant substitute for liquid fuels in the transportation sector for most of the scenarios reviewed. On the other hand, three of the scenarios reviewed for this report give explicit treatment to energy sources for hydrogen, and none considered the potential for advanced battery technology to shift transportation energy to the electric power sector in the decades ahead. The Pew Center scenarios did, however, explore the impact of plug-in hybrid vehicles, which warrant more attention in long-term global energy scenarios that include carbon emission mitigation goals.

There are quite a number of renewable energy technologies that can be integrated in buildings, ranging from solar photovoltaics to solar water heating to passive solar design elements. While decentralized solar PV is implied in a number of scenarios, solar water heating was incorporated in only a few scenarios, and passive solar design was characterized implicitly as a type of efficiency measure in most. This report reviewed scenarios at a global level and does not include a sectoral analysis. However, it should be noted that integration of renewable energy technologies with building designs remains a source of great technical potential beyond what is typically considered for renewable energy in the scenarios reviewed.

Table 3 summarizes the technology types included in the scenario sets according to the data that were available. The colored "X" marks refer to renewable technologies, while the marks in black indicate non-renewable technologies.

Table 3: Technology Types Included in Scenario Sets

	Type of Technology	IEA WEO 2006	IEA ETP	IPCC	WETO H2	WEC GES to 2050	EREC/ Green-peace	EET Eff and RE	ASES	WBGU
Renewable Electricity Sources	Hydropower	X	X		X	X	X	X		X
	Biomass	X	X	X	X	X	X	X	X	X
	Geothermal	X	X		X		X	X	X	X
	Solar	X	X		X	X	X	X	X	X
	Solar Photovoltaics	X	X		X		X	X	X	X
	Concentrating Solar Power	X	X		X		X		X	X
	Wind Energy	X	X		X		X	X	X	X
	Ocean Energy	X	X				X	X		
	Other Renewables			X		X				
	Energy Efficiency	X	X	X	X	X	X	X	X	X
	Solar Heating and Cooling		X				X	X		X
	Biofuels	X	X		X		X	X	X	
	Nuclear	X	X	X	X	X		X		X
	Hydrogen	X	X		X			X	X	X
	Carbon Sequestration	X	X	X	X				X	X

Constraints on Renewable Technologies

Global energy scenario models impose constraints on each type of energy resource (e.g., rate of growth in a particular technology or limits on total production capacity), and some models involve tens of thousands of constraints. Renewable energy technologies are typically characterized by technical potential assessed by region, and then by cost – or economic potential. Because global energy scenario models are structured to seek a combination of cost-effective energy supplies to meet a given demand, the cost characteristics assigned to each renewable energy technology are critical determinants.

However, the analysis prepared for this report was challenged by lack of data disclosure and transparency about cost assumptions. Only four of the scenario studies reviewed for this report published or provided the input cost assumptions for renewable energy technologies:

- IEA Energy Technology Perspectives --Map
- IEA World Energy Outlook 2006
- EREC/Greenpeace Energy [r]evolution
- ASES

Cost assumptions for these four scenarios are compared below in Table 4.

Table 4: Renewable Energy Cost Assumptions

RE Input Data	IEA ETP	IEA WEO	EREC Greenpeace	ASES
	(Units US$/MWh)	(Units US$/MWh)	(Units US$/MWh)	(Units US$/MWh)
Hydro < 50 MW	34 – 117	47-135		
Hydro > 50 MW	56	27-78	25 -- 115	
Biomass – Traditional	31 -- 103**	50-62**	20 – 150	
Biomass – Modern*		41-165	20 – 110	50 – 80
Solar PV	178 -- 542	313-870	250 -- 500	60 – 280
Solar Thermal (Elec.)	105-230	80-296	65 -- 240	60 – 160
Solar Thermal				***
Wind (on shore)	42 -- 221	38-78	65 – 120	30 – 70
Wind (off shore)	66 -- 217	49-82	65 – 120	
Geothermal	33 -- 97	40-60	180 -- 200	50 – 100
Ocean Energy	122	110-137		

*Modern biomass technologies (such as biogas digestion, CHP plants, cofiring, gasification, etc.) included may differ for each report. **This range may be both traditional and modern combined.
***ASES does include solar water heating but the cost numbers were part of the efficiency report that was not available at this time.

Renewable energy resources are inherently local and regionalized resources, and costs of deployment do vary by region. Since the ASES cost estimates were specific to the United States, it would not be appropriate to project them on a global scale. However, the lower cost estimates inspire curiosity about the justification for these figures, and the ASES report documents a better basis for its cost assumptions than most other scenario studies reviewed for this report. Though solar thermal water heating technology is characterized in each of these three scenarios, it is often embedded in assumptions about the potential for energy efficiency improvements in the building sector, making the cost characteristics more difficult to extract.

Closely related to energy costs are capacity factors. For electricity generating technologies, energy delivered per dollar invested is inversely proportional to capacity factor, so lower capacity factor assumptions can drive up the apparent cost of those technologies. For example, the IEA World Energy Outlook 2006 assumes a wind capacity factor of 25 to 32 percent while modern wind turbines are achieving levels of 35 to 50 percent[9] depending upon the wind resource. Such a difference could account for an apparent 40 percent difference in effective cost ($/MWh) even if the assumed installed costs were the same.

Other constraints include rate of market growth, resource availability, land availability, transmission constraints, and limits on proportion of intermittent energy. Depending upon the scenario, other constraints may be placed on biomass such as food versus fuel (land and water -- trade-offs of agricultural activity for food versus energy crops).

The ASES scenario analysis provides very clear descriptions of the constraints that were considered by each panel in evaluating the potential quantity of energy from each technology type. For example:

- **Biofuels –** Start with a percent of today's consumption and possible limitations on sources

- **Biomass –** Consider land use, food versus fuel, types of crops and subtract out any biofuel requirements

- **Concentrating Solar Power (CSP) –** Consider radiation, land use, and topography

- **Photovoltaics** – Consider radiation, conservative estimates of practical roof areas available, and possibly limit it to 10 percent of the grid energy

- **Geothermal** – Constrain by geographic availability (a self-constrained resource), and further constrain by environmental restrictions on re-injection of fluids or types of technology that can be deployed

- **Wind –** Consider land constraints and possibly constrain to 20 percent grid energy to reduce intermittency problems (or add $/MWh cost figure for grid integration)

- **Tidal –** Very geographic specific (resource self constrained)

The Role of Nuclear

Nuclear power increased in every global energy scenario, whether reference or intervention type, *unless* it was explicitly limited by the conditions of the scenario. In scenarios that involve carbon constraints, zero carbon sources of electricity are reduced to nuclear power and renewable sources of electricity. Only four scenario studies included in this review contain carbon constrained scenarios: World Energy Technology Outlook (WETO H2) - Carbon Constrained Scenario; EREC/Greenpeace energy [r]evolution; IEA

[9] Wind turbines in Oaxaca, Mexico are presently producing at the 50% capacity factor level. Report by Marco Borja, Instituto de Investigaciones Electricas, Zacatecas, Mexico, June 4 2007.

WEO 2006 BAPS, and the WBGU World in Transition: A1T–450 ppm and the B1–400 ppm stabilization scenarios. In both the WETO Carbon Constrained and the WBGU A1T–450 ppm scenarios, nuclear power as characterized in the models dominates growth among the zero carbon technologies.

However, global deployment of nuclear power is vulnerable to challenges of public acceptance, nuclear waste storage, and non-proliferation issues. Only three scenarios explored the implications of development restrictions on nuclear power: WBGU B1 Scenario, EREC/Greenpeace energy [r]evolution, and IEA ACT Low Nuclear Scenario. In both cases there is a more extensive use of renewable energy than when nuclear is not constrained. Even in carbon constrained scenarios, however, the role of renewable energy is still dependent upon the relative cost assumptions for renewables compared to nuclear and carbon capture and sequestration.

The Role of Carbon Capture and Sequestration (CCS) and Hydrogen Technologies

With coal power dominating the electric power sector and continuing to expand rapidly in China and India, a major question in future energy scenarios is "What happens with coal?" Coal use increased in all reference cases except the EET study, and coal use decreased below the reference case in every single intervention scenario reviewed. Even with the decrease below the reference cases, coal use continued to grow modestly in several intervention scenarios.

Interestingly, though carbon capture and sequestration (CCS) was mentioned in most scenario studies (7 of 10), it was only characterized for deployment in four of those studies: the ETP MAP scenarios, the IEA WEO BAPS scenario, the WBGU scenarios, and the Pew scenarios. All four of these studies aimed to chart technology paths toward low carbon futures. One inference supported by this scenario review is that CCS is a technology type with a single benefit (carbon mitigation) that will not play a major role in energy futures that lack assertive and sustained climate policy or a mix of technology policies designed to mitigate carbon emissions.

In the Appendix II Dashboards, the last panel, Fraction Disposed to Atmosphere, indicates the extent of CCS deployment in each of the scenarios profiled. For instance, the IEA ETP Map scenario implies that nearly 20 percent of all carbon dioxide generated in the energy sector worldwide will be sequestered each year by 2045. In order to meet a 450ppm CO_2 climate stabilization target in 2100, the WBGU A1T–450ppm scenario calls for CCS to sequester a mass equivalent of 30 percent of all carbon generated in the energy sector. In the WBGU B1–400 ppm scenario (where nuclear is constrained), CCS sequesters a mass equivalent of 40 percent of all carbon generated in the energy sector.[10] Cost characteristics or assumptions for CCS technology in these scenarios were not published.

[10] The WBGU scenarios include some sequestration from biomass power plants and hydrogen production facilities.

Hydrogen technologies only play a key role in the ETP Tech Plus, the WETO–H_2 and the WBGU scenarios. In the WETO–H_2 scenario, the hydrogen pathway relies heavily on nuclear power and fossil fuel paired with carbon sequestration. In the WBGU Scenarios, solar-sourced hydrogen starting in 2020 appears to have a lower cost than wind power or solar power (photovoltaic, thermal electric and solar heat), so virtually all of the displaced supply is replaced with a modest quantity of efficiency in the early periods, and new supply is replaced with a strikingly large quantity of solar-sourced hydrogen. Solar-sourced hydrogen does not appear to be characterized as a cost competitive technology option in the other scenario sets.

Energy Efficiency and Renewables

Within the context of a single building project, it is common that inefficient use of energy in general and is a waste that undermines the potential for investment in the renewable energy technology. The same logic applies to expansion of renewable energy capacity within a global energy system. Persistent use of inefficient end-use devices and systems increases the cost and quantity of supply needed to deliver those energy services and typically diminishes the portion of the global energy supply supported by renewable energy technologies.

Improvements in energy efficiency in the energy supply chains can be detected in global energy scenarios as a ratio of primary energy input per unit of final energy delivered, an Energy Supply Loss Factor. Over the 20th century, a shift toward electricity has caused this indicator to increase 0.2% per year – rather than decrease as one might expect with technological improvements in the electric power sector itself. All of the scenarios reviewed generally followed this trend except for the EET study, which reported data for Europe, an area where electrification is essentially complete. Though some scenarios may have envisioned efficiency improvements in the energy supply chains – and particularly in the electric power sector – these efficiency improvements are barely detectable in the overall performance of the energy system.

On the other hand, improvements in Final Energy Intensity of Economic Activity (final energy unit delivered per unit of GDP generated) can have a powerful influence on the global energy system and the context for renewable energy development. Final energy intensity improvements are typically achieved through end-use efficiency and structural changes to the types of energy services demanded in the economy.[11] Over the last 20 years, the global trend for final energy intensity improvement is -1.4% per year. All of the reference scenarios framed as future projections of past trends followed this trend. Some of the exploratory reference cases, such as the IPCC A2 marker scenario as well as the WEC A and B cases were much more pessimistic.

Most intervention cases reviewed accelerate the improvements in final energy intensity, but the improvements in many of these cases seemed modest compared to the dramatic

[11] This report does not investigate the division between these types of effects.

shifts suggested in the changing composition of supply (e.g., enormous CCS deployment, large-scale expansion of nuclear power, or construction of a hydrogen infrastructure). After incorporating all the policy interventions and technological improvements, most of the intervention scenarios indicated final energy intensity improvements that track the more recent global aggregate -2% per year trend of 1995-2000 – achieved without any of the interventions.

The EREC/Greenpeace [r]evolution and the ASES scenarios indicate the largest quantity of energy demand reductions via energy efficiency. In the ASES Scenario, energy efficiency contributes 57 percent of the CO_2 reductions identified.[12] In the [r]evolution Scenario, investments in efficiency have an effect on the primary energy profile that is four times larger than the contribution of new renewable energy. The ambitious description of the measures they envisioned suggests that achieving this scale of impact will be challenging.[13] The EREC/Greenpeace [r]evolution scenario is the only one that exceeded the recent global trend of -2% per year improvement, reaching -2.5% for some periods in that scenario. This aggressive role for energy efficiency helps explain why and how the renewable energy share of primary energy for this scenario is such a high outlier in the field of scenarios reviewed by this report (see Figures 1-3).

SUMMARY OF THE ROLE OF RENEWABLES IN INDIVIDUAL SCENARIOS

Renewable energy can be considered "robust" across all the scenario studies reviewed for this report, i.e., renewable energy shows up in all scenarios regardless of its relative significance within each study. The key questions explored in this report relate to the variation in the results, which are influenced by the range of renewable energy technologies included, the policy interventions imposed, the types of model and modeling assumptions, the characterizations of each of the technologies included in any scenario, and the role of non-renewable technologies in the global energy system.

The assessment of the role of renewables described in the sections above is supported by the quantitative analysis of data published for twenty six of those scenarios. Each scenario is profiled in Appendix II, *Profiles of Reviewed Scenarios*, using a single template that is described in Appendix I, *A Description of Scenario Profiles*. Most importantly, the scenario profiles begin with brief articulation of the scenario frame and its basic characteristics. Though this section compiles the key observations about renewable energy for each scenario reviewed, all of these results should be considered within their individual context as described in the complete profiles in Appendix II.

[12] For this energy efficiency savings segment, buildings made up 40 percent, transportation 30 percent, and energy efficiency in industry contributed 30 percent.

[13] It should be noted that improvements to the final energy intensity indicator in the [r]evolution scenario are entirely a result of energy efficiency, whereas some other scenario experiments also incorporate changes in the structure of the economy spurred by the policy interventions as well (e.g. a global shift toward service-oriented economic activity.)

European Commission: European Energy & Transport: Scenarios on Energy Efficiency and Renewables

These scenarios are focused on 25 European Union countries (EU-25) rather than having a global focus.

High Renewables Scenario
Biomass use dominates this scenario with the fastest growth rate, quadrupling from 2005 to 2030 (instead of the doubling indicated in the reference case). The contribution from wind also increases, but the growth rate slows after 2015, and its contribution remains a small fraction of the energy mix. The policy intervention also stimulates growth in geothermal while solar takes off after 2020. The additional renewable energy drives nearly 15 percent of the expected fossil fuel and nuclear power out of the energy mix.

Energy Efficiency Scenario
Though efficiency investments reduce the amount of energy needed from all sources in the future, those savings are not reinvested in additional renewable energy capacity in this case, so observations about renewables reflect the reference case assumptions. Biomass use dominates with the fastest growth rate, doubling from 2005 to 2030. Wind also experiences strong growth, especially compared to solar that remains a fringe technology in the mix. The reference case assumes a strikingly optimistic departure from the worldwide trend of declining supply efficiency, driven primarily by electrification. The impact of the policy interventions to promote efficiency appears not to improve supply efficiency any further.

Combined High Renewables & Efficiency
The combination of efficiency and renewables drives nearly twice as much fossil and nuclear power out of the baseline energy portfolio than using either strategy alone. Biomass use is most stimulated by the policies, and the additional efficiency available at lower cost relaxes the demand for solar power under this scenario compared to the renewable-only case. Overall, non-biomass renewables would still constitute a very small portion of the primary energy mix for the EU-25 in 2030.

International Energy Agency: World Energy Outlook 2006

Alternative Policy Case
Aside from biomass, the contribution of renewable energy sources is extremely limited. The assumed capacity factor for wind (25 to 32%) is low and the cost range is large (5 to 7.5 cents/kWh). Perhaps more importantly, the nuclear costs are relatively low (4.8 to 5.8 cents/kWh) by comparison. Wind is the only renewable energy source for which cost ranges are disclosed in this report. The WEM model indicates that the policies currently under consideration (Alternative Policy Case) would primarily motivate efficiency and conservation along with construction of additional nuclear power plants.

Beyond Alternative Policy Case
The Beyond Alternative Policy Scenario limits carbon emissions to 2004 levels in 2030, which is 8 GtCO2 below the result in the Alternative Policy Scenario. BAPS draws 2.5 GtCO2 of additional mitigation from carbon sequestration and 2.5 GtCO2 of additional mitigation from efficiency. By comparison, 1 GtCO2 comes from additional renewable energy use, half of which is hydropower. In 2030, 32% of global electricity use is attributed to renewable energy sources.

International Energy Agency: Energy Technology Perspectives

Map Scenario
This report uses a baseline that extends the IEA's World Energy Outlook 2005 beyond 2030 to 2050. However, the primary energy data for the reference case indicate a sharp departure from the published trends through 2030 with an aggressive increase in the quantity of coal consumed. Thus, the improvements in the Map Scenario barely regain the market share for renewables and overcome the aggressive acceleration of coal consumption in the latter part of the baseline. With the exception of hydropower, data for renewable energy sources are reported as a combined quantity. Efficiency improvements in the Map scenario are significant, reducing demand by nearly 25 percent. The Map Scenario implies that nearly 20 percent of all carbon dioxide generated in the energy system will be sequestered each year by 2045.

European Commission: World Energy Technology Outlook

Carbon Constraint Scenario
The POLES model indicates that a carbon constraint would induce deployment of carbon sequestration and more nuclear power, having only a very modest effect on the contribution of renewable energy technologies to the total energy portfolio. By 2050, renewables and nuclear each provides more than 20 percent of the total demand; renewable sources provide 30 percent of electricity generation and nuclear electricity nearly 40 percent. Despite limiting growth in coal consumption by adding nuclear power capacity and some renewable generating technologies, the scale of coal usage at 1990 still persists throughout the scenario time period via the large-scale deployment of carbon capture and sequestration.

Towards a Hydrogen Economy
The transition towards a hydrogen economy pathway described in this scenario ultimately relies heavily on nuclear power and fossil fuel paired with carbon sequestration. For all the expense of hydrogen technologies and carbon sequestration, improvements in energy efficiency appear understated. Because solar plays an absolutely negligible role in the reference outlook, the hydrogen technology breakthroughs do have positive implications for solar and biomass, but growth in the wind industry is hardly affected at all. The solar industry appears almost dormant until 2030, at which point growth in the use of modern biofuels also increases dramatically.

European Renewable Energy Council & Greenpeace: Energy [r]evolution

[r]evolution
Investments in efficiency have an effect on the primary energy profile that is four times larger than the contribution of new renewable energy. The challenge of achieving this scale of impact is indicated by the sustained improvements to primary energy intensity of economic activity in the [r]evolution scenario, which exceeds the highest rates of improvement observed at the global level in the last three decades. Because the expectations for wind, solar, and geothermal energy are negligible in the reference case, the [r]evolution scenario does show remarkable increases in the capacity of each starting in 2010. Though the renewables numbers are high, this is to some extent due to the dramatic decrease in primary energy rather than aggressive renewable energy growth. Among the renewable energy technologies, solar power has the most aggressive growth profile, which declines from an annual rate of 23 percent in 2010 to 3 percent in 2050.

Intergovernmental Panel on Climate Change: Special Report on Emissions Scenarios

A2 Emissions Scenario
Renewable energy technologies play a negligible role in the global energy system overall, but the rate of expansion for biomass is still remarkable. The stress on the entire system is aggravated by the surprisingly pessimistic treatment of efficiency in the modeling team rendition of an A2 future. Conceptually consistent with an important theme of the A2 storyline, efficiency is perhaps the most quintessentially local resource. The ASF model indicates that coal and natural gas are cheaper than efficiency on a scale that is triple the current rates of consumption, which does challenge the imagination – and diminish the relative contribution of renewable energy technologies of any type.

B1 Emissions Scenario
Solar power and biomass are the only two renewable energy resources that are characterized in this model and experience any growth in this scenario. The component of solar power is merged with nuclear power in the data reporting for this scenario, which challenges the analysis. Nuclear power, solar power, and biomass all experience a surge as production of oil peaks and growth in consumption of coal and natural gas stabilizes.

A1B Emission Scenario
Biomass begins the century in decline because traditional, non-commercial use is in a state of decline. Then modern biofuels launches, and the component of solar and wind (reported in the same category as hydropower) also surge from 2030 to 2050. Despite the fact that biomass and solar (with hydro) reach such a scale and attain such a high rate of growth by mid-century, they are still not even able to keep pace with the marginal increase in demand each year under the conditions of this scenario.

World Energy Council & IIASA: Global Energy Perspectives

The WEC scenarios were first explored in 1993, laying the conceptual groundwork for the more widely-used IPCC scenarios developed five years later. Many of the core assumptions, long-term trends, and modeling techniques have been revised since these scenarios were published.

Case A Scenarios (A1 and A3)
These two cases contrast technology development paths that treat traditional biomass and hydropower similarly in both cases. All "new renewables" – including modern biofuels – are reported as a single category. In the A3 case, the average annual rate of increase varies between 3 – 9 percent, driving the renewables share of primary energy above 30 percent by 2050. In comparison to the oil and gas case (A1), the nuclear renewables case (A3) appears to have a much larger effect on natural gas than either nuclear power or renewables.

Case B Scenario
Traditional biomass declines and hydropower increases along long-term prevailing trends. All "new renewables" – including modern biofuels – are reported as a single category. In the B case, the average annual rate of increase varies between 3 – 7 percent, driving the renewables share of primary energy above 20 percent by 2050.

Case C Scenarios (C1 and C2)
As in Scenarios A and B, these two cases contrast technology development paths that treat traditional biomass and hydropower similarly in both cases, following long-term trends. All "new renewables" – including modern biofuels – are reported as a single category.

Lower overall demand is a striking difference in the C cases compared to A and B. The C cases feature a rate of improvement in final energy intensity of economic activity that matches the prevailing global trend from 1980 to 2000, while the A and B cases are more pessimistic. As a result, the development of "new renewables" can proceed at a pace similar to the B case, but claim approximately twice the share of the global energy portfolio. (Approximately 40 percent of all energy is delivered by some form of renewables by 2050.) The C1 case indicates that in the absence of the additional nuclear power capacity included in C2, the substitution of renewables is approximately 40 percent.

German Advisory Council on Global Change: Climate Protection Strategies for the 21st Century: Kyoto and Beyond

A1T – 450 ppmv Scenario

Use of renewable energy technologies – and especially the dramatic entrance of solar-sourced hydrogen – in the exploratory reference case (A1T) are extensive even before a constraint on carbon emissions is imposed. The carbon constraint to 450 ppm drives 25 percent fossil fuels (mostly coal) out of the global energy mix by 2050. These supplies are largely replaced with improvements to efficiency. Though the improvement to final energy intensity of the economy appears small, the leverage on the system is large. The MESSAGE model characterization of solar-sourced hydrogen starting in 2020 appears to have a lower cost than wind power or solar power (photovoltaic, thermal electric, and solar heat), so virtually all of the new supply is solar-sourced hydrogen. To meet the climate stabilization target, carbon sequestration in 2050 reaches a mass equivalent of 30 percent of all carbon generated in the energy sector.

B1 – 400 ppmv Scenario

Compared to all other reference cases reviewed in this report, the use of renewable energy is most extensive in this exploratory reference case because the B1 storyline describes a relatively low-carbon future – or a type of best-case scenario for climate change in the absence of climate policy. The carbon constraint to 400 ppm drives even more fossil fuels out of the global energy mix, and the limits placed by WBGU on other alternatives results in declining contributions from biomass, hydropower, and nuclear power. The MESSAGE model characterization of solar-sourced hydrogen starting in 2020 appears to have a lower cost than wind power or solar power (photovoltaic, thermal electric, and solar heat), so virtually all of the displaced supply is replaced with a modest quantity of efficiency in the early periods and a strikingly large quantity of solar-sourced hydrogen. To meet the climate stabilization target in 2050, carbon sequestration in this scenario reaches a mass equivalent to 40 percent of all carbon generated in the energy sector.

Shell Global Scenarios to 2025 -- The Future Business Environment: Trends, Trade-offs and choices[14]

This scenario set provides insights into the kinds of strategies different groups may adopt in different strategic contexts. The importance of carbon in overall policy strategy and market environment is considered a "predetermined trend." But there are key uncertainties:

- Extent to which U.S. states adopt policies aimed at carbon reduction
- Prices for carbon emission rights

[14] Quantitative data were not readily available to allow us to do a more in-depth analysis of this scenario set.

- Type of support for the development of new technologies
- The effectiveness of market mechanisms in reducing carbon emission growth
- The level of global integration and reach of the offset market; and
- How fair the carbon reduction objectives are perceived to be by developing economies and their willingness to accede to these

The energy scene is being transformed under the impact of a triple discontinuity reflecting qualitative changes in the three forces at the apexes of the Trilemma Triangle (Efficiency, Security, and Social Cohesion and Justice). On the market side, three decades of delinking of economic growth and energy consumption are giving way to strong 'relinking' as the largest share of new demand comes from developing economies. Forces of coercion and regulation, meanwhile, reflect a new awareness that energy supply will come from unconventional energy sources and from more challenging regions. Growing concerns over detrimental climate change make carbon management a pillar of the emerging energy-and-carbon industry.

> "Renewables have the potential to meet all energy needs, at least in theory. Altogether, as discussed in the three scenarios, policies, regulations and behaviors, as well as relative costs will set the real limits for the use of renewable energy sources." (p. 212)

The three scenarios were:

Low Trust Globalization
This scenario describes a legalistic world with the emphasis on security and efficiency even at the expense of social cohesion.

Open Doors
This is a pragmatic scenario that emphasizes cohesion and efficiency with the market providing "built-in" solutions of security and trust.

Flags
In this scenario, security and community values are emphasized at the expense of efficiency.

The Pew Center on Global Climate Change -- U.S. Energy Scenarios for the 21st Century[15]

The focus is on the relative difficulty of implementing a carbon constraint policy under three quite different circumstances. The value of these scenarios will be their ability to stimulate decision makers to explore alternative views of the energy future and to facilitate strategic planning and policy making in uncertain times.

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[15] This scenario was only reviewed and not quantitatively evaluated.

Fuel cells, hydrogen (particularly in the transportation sector), energy efficiency and distributed generation technologies play key roles in these scenarios. Nuclear power plays a significant role in each of the scenarios with and without the policy overlays. Geological sequestration emerges as a key technology allowing continued reliance on fossil fuels even in the face of a carbon constraint. Hybrid-electric vehicles play an important role in the transportation sector as a bridge technology for fuel cells in mobile applications.

Key insights include: (1) Policy is necessary to address climate change; (2) there are technologies (with supporting policies and investments) that could address climate change, accelerate capital stock turnover, and enhance the nation's energy security, no matter which direction the future takes. (3) The scenarios indicate that energy policy and investment decisions made today affect the difficulty of implementing a climate policy tomorrow.

The Pew scenarios put greater emphasis on distributed renewable generation than most other scenarios (and than they do on conventional renewable generation). The primary barriers that distributed generation must overcome are:

- Regulatory inertia
- True costs of integrating and interconnecting DG with a largely centralized structure; and
- Resistance to distributed generation by centralized utilities who may view it as a competitive threat.

The three scenarios included in this set were:

Awash in Oil and Gas
In this scenario the U.S. energy sector is left largely to market forces.

Technology Triumphs
This scenario is driven by market forces, technology innovations, and policy decisions.

Turbulent World
This presents an event driven scenario, characterized by severe stresses and broad challenges.

American Solar Energy Society: Tackling Climate Change in the U.S.

Potential Carbon Emissions Reductions from Energy Efficiency and Renewable Energy by 2030

Unlike any of the other energy scenarios that depend upon complex computer modeling, this scenario used a bottom-up engineering approach that incorporated reports developed by nine expert panels (Energy Efficiency, Concentrating Solar Power, Photovoltaics, Wind Power, Biomass, Biofuels and Geothermal).[16] The purpose of this scenario exercise was to look at energy efficiency and renewable energy technologies to determine the potential carbon reduction for each. The authors were asked to describe the resource, discuss current and expected future costs, and develop supply and carbon-reduction curves for the years 2015 and 2030.

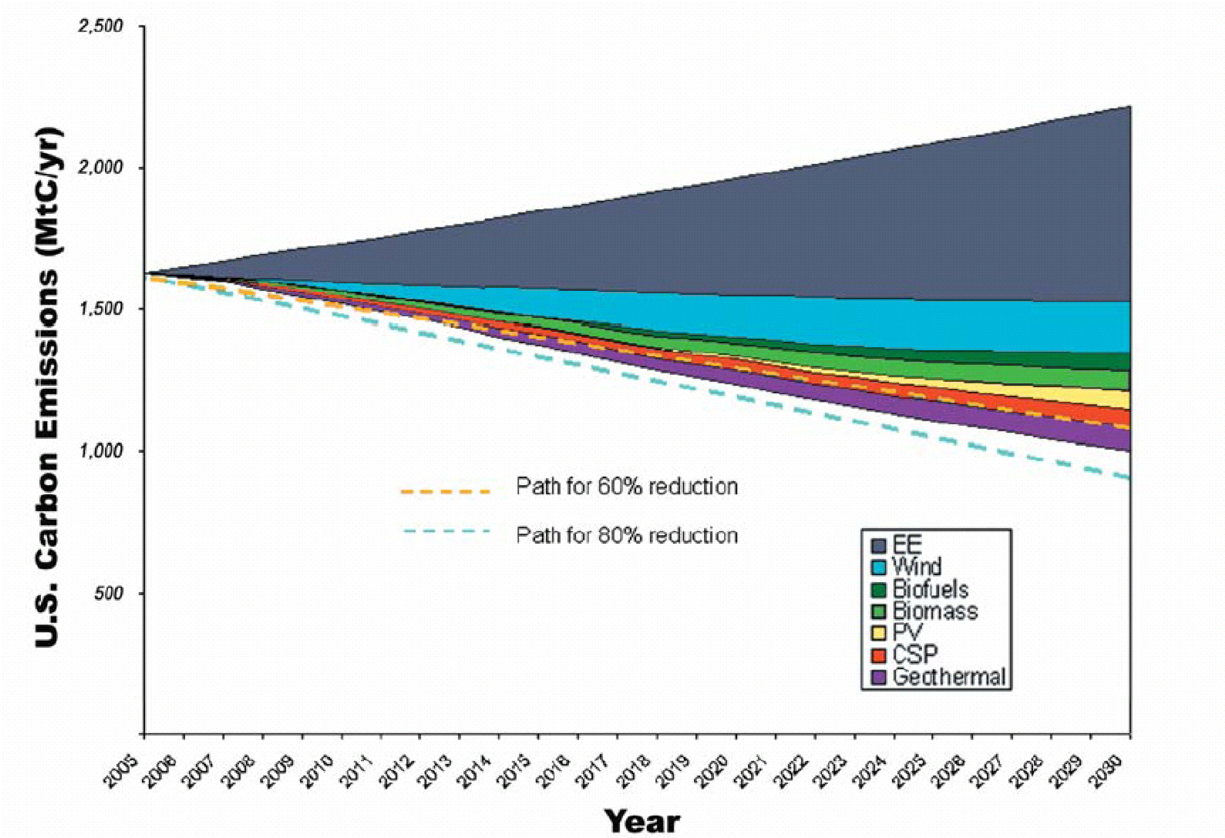
This scenario was the most transparent of all the scenario sets reviewed. It provided all the relevant cost and capacity factors in the report though they were submerged within the text in each section... The results of these studies show that renewable energy has the potential to provide approximately 40 percent of the U.S. electric energy need projected for 2030 by the Energy Information Administration (EIA). After reducing the EIA electricity projection by taking advantage of energy efficiency measures, renewables could provide about 50 percent of the remaining 2030 U.S. electric need.

There are uncertainties associated with the values estimated in the papers, and, because these were primarily individual technology studies, there is uncertainty associated with combining them. The results strongly suggest, however, that energy efficiency and renewable energy technologies have the potential to provide most, if not all, of the U.S. carbon emissions reductions that will be needed to help limit the atmospheric concentration of carbon dioxide to 450 to 500 ppm.

This scenario exercise is important for a number of reasons: (1) The cost and technology data are readily available for review allowing apples to apples comparisons with other scenario data sets; (2) because of the transparency of the assumptions and the rigor with which they were developed, it is possible for other scenario modelers to compare their own assumptions to justify differences or revise accordingly; and (3) this scenario presents an aggressive but credible view of the contribution that renewable energy could make, relying heavily on prioritized investments in efficiency. For this reason, it should be valuable to U.S. decision makers as they consider the energy options available under a carbon constrained future.

[16] Not covered was active solar space and process heat, offshore wind, ocean power, or electric storage for wind or PV.

Figure 4: Carbon emission savings results from the ASES scenario



OBSERVATIONS AND RECOMMENDATIONS

What energy future we ultimately experience is the result of choices; it is not fate. Policy makers, investors and consumers do have choices, and every indication in the headlines today is that their decisions are not tracking to the trends of the past. Energy scenarios can help these decision-makers evaluate the available options and the potential implications of their choices.

To gauge the credibility of scenario results, it is important to assess the validity of the assumptions inherent in a model's structure as well as the values of key parameters. Because third party analysts rarely have the benefit of time and expertise to conduct a multi-model investigation, this report uses a different approach to survey implicit assumptions apparent in the results, an initial layer of assessment. The dashboard diagrams in Appendix II, Profiles of Reviewed Scenarios, serve as a tool to help accomplish that goal and fulfill the purpose of this report. Having completed that analysis, the authors suggest seven overarching recommendations to modeling teams constructing future global energy scenarios.

Recommendation #1 – Data Transparency
Scenarios explore the prospects for various options in the contexts of different possible futures. Information about the way those options are characterized is vital to understanding the results. In addition to energy scenario output data, data inputs should be transparent and publicly available with the scenario results. Completion of this review was challenged by unpublished data for cost and performance assumptions describing individual renewable energy technologies over the next two to four decades.

Recommendation #2 – Articulation of Scenario Frame
Clearly describe the scenario frame – the question the scenario seeks to answer. Most of the scenarios were good about this, though some required more effort to identify the question being asked. Though the IEA World Energy Outlooks and the IPCC SRES scenarios both generate reference cases that serve as baselines for comparison, they are critically different *types* of scenarios, and audiences need to be able to readily distinguish between them rather than dismissing the results of one or the other.

Recommendation #3 – Expanding the Range of Renewable Energy Technologies
Energy scenarios should include a variety of renewable energy technologies in order to fully explore the range of options available for reducing carbon emissions from the energy sector. Reporting renewable energy technologies as an aggregate figure in scenario results deprives analysts the opportunity to distinguish among the distinct technology options. In this review, those scenarios with a broader and more detailed characterization of renewable energy technologies also tended to yield results that indicated greater use of those technologies in the future.

Recommendation #4 – Characterization of Renewable Energy Technologies
The ASES report provided the most detailed characterization of each type of renewable energy technology, prepared by industry experts. Because this type of information is essential to judging the validity of the results, all other scenario reports should use the ASES study as a minimum standard for detail and disclosure. Although the technology assumptions used by other institutions will inevitably differ, the ASES report poses a challenge to other scenario teams to more explicitly state and justify those differences in assumptions.

Recommendation #5 – Role of Efficiency
Whether using a macroeconomic “top down” approach or an engineering-economic “bottom up” approach to energy system modeling, scenario development teams should reference metrics for final energy intensity of economic activity (which includes demand-side efficiency) and energy supply loss factor (which indicates aggregate supply-side efficiency) to evaluate the impact of policy interventions. Comparing the potential for efficiency improvements to the scale of impact on other technology options can help identify apparent mismatches in level of effort, and therefore the potential. Larger investments in efficiency will tend to diminish the scale of investments in CCS, for instance, and increase the apparent scale of contribution renewable energy can make across many possible long-term energy futures.

Recommendation #6 – Description of Model Features
Scenario studies should clearly describe the model used (or the process if no computer model was used) and the relationships between the principle factors. Due to differences in model structures and assumptions, two models of the global energy system using essentially the same set of historical data and with the same scenario frame can come up with answers that still differ. Therefore, clearly describing the model and the relationships between the principle factors can yield important insights into the way renewable energy technologies are selected for deployment by each model.

Recommendation #7 – Carbon Constraints and Climate Policies
Most of the scenarios selected for review did not consider explicit climate policies or limits on carbon emissions from the energy sector. However, greenhouse gas emissions are a major challenge to society, and the energy sector will be the most affected by any political and technological solutions. Therefore, those scenarios that do consider the impact of climate policies may be considered more relevant to long-term policy and investment decisions.

Final Thoughts

Because scenario analysis is designed to explore uncertainty rather than reduce it, it is more helpful to seek scenarios that can be validated within the imagined context of each – rather than compared to a single future history as "right" or "wrong." Part of that validation must involve full disclosure of assumptions about renewable energy technology development and a review of the justifications for each assumption in the characterization of each technology. Based on the published data included in the reports for each of the scenario studies selected for review, such an investigation could not be completed. However, observations of incomplete renewable energy technology sets and undisclosed technology assumptions suggest that many scenario studies have yet to explore the full potential for renewable energy.

The scenarios reviewed do support some valuable observations for the field of scenario analysts and an audience of scenario users interested in the role of renewable energy. First, the reference scenarios reviewed in this report tend to suggest a relatively modest role for renewable energy technologies four decades in the future. Second, even after applying a number of imagined policy interventions or technology innovations, most of the intervention scenarios indicated 80% of the primary energy portfolio in 2050 would still come from non-renewable sources. The IEA ETP study and the EREC/Greenpeace [r]evolution scenario are notable exceptions, indicating much more aggressive deployment of renewable energy technologies. The two general observations above lead to two different types of interpretations:

1. The models generating the scenarios reviewed accurately describe the energy-economic system as well as the intervention policies. Therefore, the relatively minor role of renewable energy (and the persistent large-scale use of fossil fuels)

indicates that the policies presently proposed are inadequate to the task of meeting the climate challenges – <u>something far more bold is required.</u>

Or,

2. The relatively minor potential for renewable energy technologies in the results of an intervention scenario suggests that its modeling assumptions do not accurately capture the changing market conditions, the rate of technological innovation, and the stimulus of multiple policy interventions.

The published reports representing each of the scenarios reviewed did not include a sufficient level of input data or technology characterization to draw either conclusion for each individual scenario. However, this report frames the considerations that would apply to such an evaluation for all of them, a product that is intended to contribute to the development and evaluation of future global energy scenarios.

Those scenarios that do feature the most significant contribution from renewable energy technologies draw heavily on energy efficiency improvements as well. Among the renewable energy sources, biomass was routinely reported to dominate the other options. However, few scenarios include a full range of renewable energy and efficiency options. Exploring the full potential of these options can offer a decision-maker striving to achieve energy security, sustainable development, and climate stabilization a broader range of energy opportunities, many of which are available today. Whereas some technologies only respond to explicit climate policies (e.g. carbon sequestration or solar-sourced hydrogen), the combination of renewable energy and energy efficient technologies supports all three of those overarching objectives for the 21st century.

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Appendix I: Description of Scenario Profiles

I.1. Introduction

This report reviews the results of sixteen different energy futures generated by eight different models in eight different studies.[1] Although most of these scenarios are not directly comparable to each other in purpose or result, each of them does provide some relevant insight into the overarching inquiry of this report: the role of renewable energy in long-term energy scenarios. Because of these differences, it is essential to consider the results in an effective and consistent framework for interpretation. Appendix II uses four narrative elements and three quantitative elements to profile each sample scenario, and the purpose of this Appendix I is to briefly introduce each element. The closing section of this Appendix includes important remarks on the treatment of GDP and primary energy accounting, which are pervasive issues in long-term energy scenario analysis and the comparability of results.

I.2. Narrative Elements of Scenario Profiles

Each scenario profile includes the following narrative elements: scenario frame, scenario description, model description, and key observations relevant to this report. These brief passages are clearly no substitute for the full breadth and depth of the documentation provided by the original, cited publication for each scenario. However, they do provide essential context for the quantitative elements, which could show similar *data* for two cases that have a very different *meaning*. The brief narrative passages are intended only to flag for a reader some of the influential aspects of the scenario design that can help put its results into context.

I.2.1. Scenario Frames

One of the main challenges to the policy relevance of scenario analysis is confusion about the context of inquiry. A *scenario frame* answers the question, "What type of future does this scenario explore?" Results generated by studies exploring different scenario frames may defy meaningful direct comparison. However, many scenarios that explore how conditions could change from current trends in a hypothetical future (intervention scenarios, or alternative scenarios) are compared to a scenario that explores a future in which present conditions persist (reference scenarios). Many of the scenarios profiled in Appendix II take this form, and the scenario frames for both the reference and the alternative case are included.

[1] Because four different reference scenarios are included in the analysis, and the World Energy Council scenarios include two variations of two cases, the total number of scenarios characterized in this report is twenty two in total.

I.2.2. Scenario Description

The scenario description is an extracted quotation or an abstract of a passage in the more detailed documentation provided in the original, cited publication. While the brevity of the descriptions makes them an incomplete reflection of the underlying system dynamics assumed by scenario modeling teams, the scenario descriptions are intended to give the reader a sense of the most influential or striking features of the reference future and its alternative.

I.2.3. Model Description

A scenario based on a common frame but generated by different models may yield different results, which reflects uncertainty about the models and the relationships they are designed to represent. The scope of this report does not include an investigation of different modeling techniques, so the short description of each model is prepared simply as a reminder that model assumptions in the quantitative analysis of each scenario can be responsible for a great deal of the differences between results.

I.2.4. Key Observations about Renewable Energy

Each profile concludes with a brief comment on the role of renewable energy in the quantitative elements of the scenario profile. Because the role of energy efficiency has a material affect on the share of energy demand served by renewable sources, some of the observations include efficiency as well.

I.3. Quantitative Elements of Scenario Profiles

Each scenario profile includes three quantitative elements: a primary energy profile with three panes, a line graph indicating the share of renewable energy in the primary energy portfolio, and a dashboard of key drivers of carbon emissions, which has five panes. Unless otherwise noted, all of the data is at the global level. The quantitative elements for each scenario profile are based on published data in the public domain. For example, data tables in the appendices of scenario publications served as the primary source for data in the scenario profiles of Appendix II.

I.3.1. Primary Energy Profile

The primary energy profile is a familiar standard in the presentation of scenario results, and the profiles in Appendix II include a side-by-side comparison of reference and alternative cases. The third pane of the primary energy profile is a stack chart designed by Jae Edmonds at Pacific Northwest Laboratories to show how changes in the conditions of a reference future affect individual energy resource types.

All three of these panes share a common legend for a single scenario profile, but the legends frequently differ between scenarios. This variation reflects another important variation in scenario analysis: assumptions about available technology options. If a particular technology (e.g. wind power) is included in the legend, then it was available in the scenario – even if the results indicate the contribution from that technology is too small to be visible in the primary energy profile.

I.3.2. Renewable Energy by Type

The main body of this report includes line graphs that compare the total quantity of renewable energy as a share of primary energy or electric power generation, and by necessity, the variation between renewable energy technology types cannot be observed in these multi-scenario graphs. Therefore, the scenario profiles in Appendix II serve as a source of additional detail, illustrating not only the relative scale of contribution between technology types but also the implicit growth rates for these industries in the models.

I.3.3. Dashboard of Key Carbon Emission Drivers

I.3.3.1. Dashboard purpose

Though only three of the alternative (or intervention) scenarios reviewed in this report place an explicit limit on carbon emissions, every single one of the scenarios reported carbon emissions as a key characteristic of the results. As an analytic exercise, construction of emissions scenarios is closely linked to the construction of energy scenarios, and therefore, the disaggregation of key drivers of emissions can also reveal valuable insights regarding key assumptions about the scenario outside of the energy sector such as differences in population and economic growth trends.

Two basic questions start a line of inquiry into the details of energy and emission scenarios:

How do key drivers of emissions differ between the uncertain futures that scenarios explore?

What effect does a policy intervention have on the key drivers for future emissions?

I.3.3.2. Elements of the dashboard

The dashboard of key drivers is an interpretive technique that provides a basis for answering these questions. Specifically, it serves as a concise visual summary of major factors influencing carbon emissions, including changing trends in the energy sector.[2] The factors considered are:

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[2] The decomposition presented in Appendix II is adapted from a convention called the Kaya Identity, credited to Dr. Yoichi Kaya who presented it at a 1991 meeting of the Intergovernmental Panel on Climate Change. The visualization concept used to present the decomposition elements as a series of line graphs is adapted from the User Support System developed by the Dutch Department of Environment to explore results from its IMAGE 2.2 scenario

- population (P)
- gross domestic product (GDP)
- final energy (FE)
- primary energy (PE)
- total carbon (TC)
- carbon emitted to the atmosphere (C)

These factors are related to one another in a series of metrics that form the basis of the graphical indicator in each pane of the dashboard:

- economic activity per capita (GDP/P)
- final energy used per unit of economic activity (FE/GDP)
- energy supply loss factor (PE/FE)[3]
- fraction of carbon emissions released to the atmosphere (C/TC)[4]

Because these metrics are a result of a disaggregation of forces driving carbon emissions, their product is equal to the total quantity of carbon emissions. In equation (1), the individual elements (e.g. P, GDP, FE, PE, and TC) cancel out as they appear in both the numerator and denominator. Therefore, the dashboard is a graphical illustration of a mathematical identity:

$$C = P \bullet \frac{GDP}{P} \bullet \frac{FE}{GDP} \bullet \frac{PE}{FE} \bullet \frac{TC}{PE} \bullet \frac{C}{TC} \qquad (1)$$

I.3.3.3. Vertical scale of the dashboard panes

Because the scale and absolute values of the individual factors vary widely[5], it is important to normalize each of them to the base year in order to make accurate observations about their relative influence on the scenario results. The scenarios reviewed in this report are treated as having a common base year, so

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model. Further documentation, analysis, and examples are included in a dissertation prepared by Holmes Hummel on “Interpreting Global Energy and Emission Scenarios: Methods for Understanding and Communicating Policy Insights,” Stanford University, 2006.

[3] Literally interpreted, this is the amount of primary energy input per unit of final energy delivered.

[4] This metric serves as an indicator of carbon sequestration in the energy system. If any of the carbon dioxide produced by the combustion of fossil fuels is sequestered rather than released to the atmosphere, then this fraction falls below 1. Otherwise, 100% of the carbon dioxide generated is release to the atmosphere.

[5] For instance, GDP per capita may range from \$3000 to \$20000 while the energy supply loss factor may range from 1.2 to 1.4.

vertical scale on each dashboard pane is indexed to the year 1990. Assumptions about future economic activity per capita (GDP/P) in the scenarios reviewed tend exceed a doubling before 2050. Therefore, the vertical scale of that one pane in the dashboard is expanded from 0 to 6 (rather than 0 to 2) in order to accommodate the most ambitious of the sample scenarios and maintain comparability between scenarios.

I.3.3.4. Lines plotted on the dashboard

In each dashboard pane, the reference case is represented by a black line and the alternative (or intervention) case is represented by a red line. These values can be compared to the trajectory for each metric that is charted by the dashed lines, which reflect the currently prevailing rate of change for selected metrics: final energy intensity of the economy, losses in the supply of final energy, and the rate of decarbonization observed in the global energy supply profile. Departures from the prevailing trends warrant special attention since they are clear indicators of significant changes in the evolution of the energy system in the 21st century.

The variety of baseline assumptions explored in the scenarios can be observed by comparing the black reference lines between different scenario profiles. The effect of the interventions proposed in a single scenario study can be observed by comparing the reference case (black line) to the alternative case (red line), where the difference is shaded in light blue.

I.4. Additional Notes

I.4.1. Primary Energy Accounting Methods

The primary energy data used in this review of scenarios is *as reported* in the original, cited publication of each scenario. The inconsistent primary energy accounting treatment *does have a material effect* on the appearance of the primary energy profiles of the scenarios profiled in Appendix II. This section describes the cause of this difference and its impact.

Some non-thermal sources of electricity are first available to the energy system at the level of final energy (electricity), and therefore, some method of calculation must be applied to determine the contribution of these sources to primary energy. The thermal equivalent method presumes that the electricity would otherwise have been generated by a fossil fuel power plant, and it applies either a substitute or a standard thermal efficiency factor (e.g. 33%) to assign a primary energy quantity to each unit of final energy delivered from such a source. The direct equivalent method, on the other hand, assigns a quantity of primary energy that is exactly equivalent to the heat content of the electricity (or hydrogen) delivered as final energy.

Until the mid-1990's, the thermal equivalence convention was most common. However, participants in the IPCC Special Report on Emissions Scenarios found that this method inflated the apparent contribution of non-thermal electricity sources to the global energy mix as they increased over time. Therefore, the IPCC scenarios do not use the thermal equivalent method, and instead, apply the direct equivalent method to all non-thermal sources of electricity or hydrogen – including nuclear power, hydropower, solar power, and wind power.

The IEA Energy Statistics Manual gives guidance to energy analysts that suggests a mix of the two methods. The "IEA Primary Energy Accounting" regime suggests the thermal equivalent method be applied to nuclear and geothermal power, and that the direct equivalent method be applied to solar power, hydropower, and wind power.

Detailed data on final energy is required to complete the reconciliation of primary energy accounting methods across multiple scenarios generated by models using different accounting regimes. This type of data – including electricity by source and input of primary energy to the electric power sector by source – is not commonly published with the data sets reported for long-term energy scenarios, and it was not included in most of the data sets used for this review of results. *Therefore, the primary energy data reported was used "as is", without any modification to reconcile different primary energy accounting regimes between studies.*

In general, those scenarios based on an IEA World Energy Outlook use the mixed "IEA Primary Energy Accounting" regime, and those scenarios based on an IPCC Special Report on Emissions Scenario reference case use the "direct equivalent method" for all non-thermal sources of electricity and hydrogen. *The main difference between these two is the treatment of nuclear power.* Because the IEA Primary Energy Accounting regime treats nuclear as a thermal energy source, the contribution of nuclear power in the IEA-based scenarios *will appear three times as large* in the primary energy profiles as it would if it were converted to the direct equivalent terms of the SRES-based scenarios. Conversely, the conversion of the SRES-based scenarios would result in *roughly a tripling* of the apparent contribution of nuclear power to the global energy resource mix as illustrated in the primary energy profiles.

All of the scenarios treat hydropower, solar power, and wind power as direct equivalent sources, which has an impact on the appearance of gains in efficiency. As thermal sources of electricity are replaced with these renewable energy technologies, the primary energy data implies an artificial efficiency gain on the ratio of 2:1 for every new unit of renewable energy (i.e. replacing a coal power plant with 33%

efficiency with solar power, which has an apparent efficiency of 100% in the direct equivalent accounting regime.)

No attempt has been made to address this issue here for two reasons. First, this error is only generated in alternative (or intervention) scenarios in which there is extensive fuel switching from fossil fuels to non-thermal renewable energy sources. Therefore, none of the singular reference cases published by WEC or IPCC are affected. Except for the WBGU scenarios, the gains in renewable energy in all of the intervention scenarios reviewed in this report are dominated by biomass (a thermal source) and the relative gains for hydropower, solar power, and wind power remain small in the global scale. Under these circumstances, conversion of the data to direct substitution regimes would have a trivial effect on the results and the findings of the report. However, solar-sourced hydorgen is a direct equivalent source in the WBGU scenarios, which rely almost entirely on new solar-sourced hydrogen to offset displaced fossil fuel use. Therefore, the distortion of gains in efficiency, which is applicable to all scenarios in this review, is only material in the WBGU scenario.[6]

I.4.2. Basis for GDP data: PPP vs. MER

The GDP data used in this study is *as reported* in the original publication for each scenario.

Some scenarios use a purchase power parity basis for economic data (e.g. those scenarios based on an IEA World Energy Outlook) and other use market exchange rates (e.g. all of the IPCC, WEC, and WBGU scenarios). Because no investigation of comparative welfare between regions is made in this analysis, the impact on the global trend and the findings of this report were not considered of sufficient magnitude to endeavor to reconcile the accounting methods in these data sets.

[6] For example, some of the 200 EJ reduction in primary energy by 2050 in the A1T*-450 scenario is actually a result of this type of substitution of a thermal energy source with a direct equivalent source.

Review of renewable energy in global energy scenarios

Appendix II: Profiles of reviewed scenarios

	Scenario Name	Study Title	Sponsor
II.1	High Renewables	European Energy & Transport: Scenarios on energy efficiency and renewables	European Commission
II.2	Energy Efficiency		
II.3	Renewables + Efficiency		
II.4	Alternative Policy Case	World Energy Outlook 2006	International Energy Agency
II.5	Beyond Alternative Policy		
II.6	Map	Energy Technology Perspectives	International Energy Agency
II.7	Carbon Constraint	World Energy Technology Outlook	European Commission
II.8	Hydrogen Development		
II.9	Energy [r]evolution	Energy [r]evolution	European Renewable Energy Council & Greenpeace
II.10	A2	Special Report on Emissions Scenarios	Intergovernmental Panel on Climate Change
II.11	B1		
II.12	A1B		
II.13	A1, A3	Global Energy Perspectives	World Energy Council & IIASA
II.14	B		
II.15	C1, C2		
II.16	A1T*-450ppm	World in Transition	German Advisory Council on Global Change (WBGU)
II.17	B1*-400ppm		

Currency

All financial figures have been converted to terms of U.S. dollars in the year 2000 (2000$US).

Use of linear interpolation

Most scenario studies reported data at even intervals of five or ten years. In order to maintain consistency in the representation of results, linear interpolation has been used to calculate data points for time periods not explicitly reported in scenario data tables. For example, if data is reported for 2000, 2003 (most recent data available at time of study), and 2010, then the data point for 2005 is interpolated.

II.1 High Renewables, European Energy and Transport (2006)

Reference case How could the European Union (EU-25) energy system evolve if only the current set of policies persist through 2030?

Alternative case What would be the implications for the EU-25 energy system of imposing a target of a 12% renewables share in 2010 and 20% in 2020?

Scenario narrative This baseline (*EET Trends to 2030, update 2005*) assumes that present policies will be implemented, though without assuming that specific renewable energy targets will be met. The scenario does reflect the decision of some member countries to phase out nuclear power. The price of crude oil is presumed to exceed US$50 (in 2005 dollars) through 2030, economic growth persists at 2%, and population growth for the region is low.

While the Renewable Energy Case shares all of these features, it also reflects the implementation of EU Directives on electricity and biofuels, as well as the effect of significant biomass/waste contribution in industry and considerable penetration of solar water heating in the household and tertiary sectors. The policy interventions described in half a dozen EU policy documents are numerous, so rather than recount them here, the reader is referred to the summary and references on pages 26-28 of the EET EE & RE report.

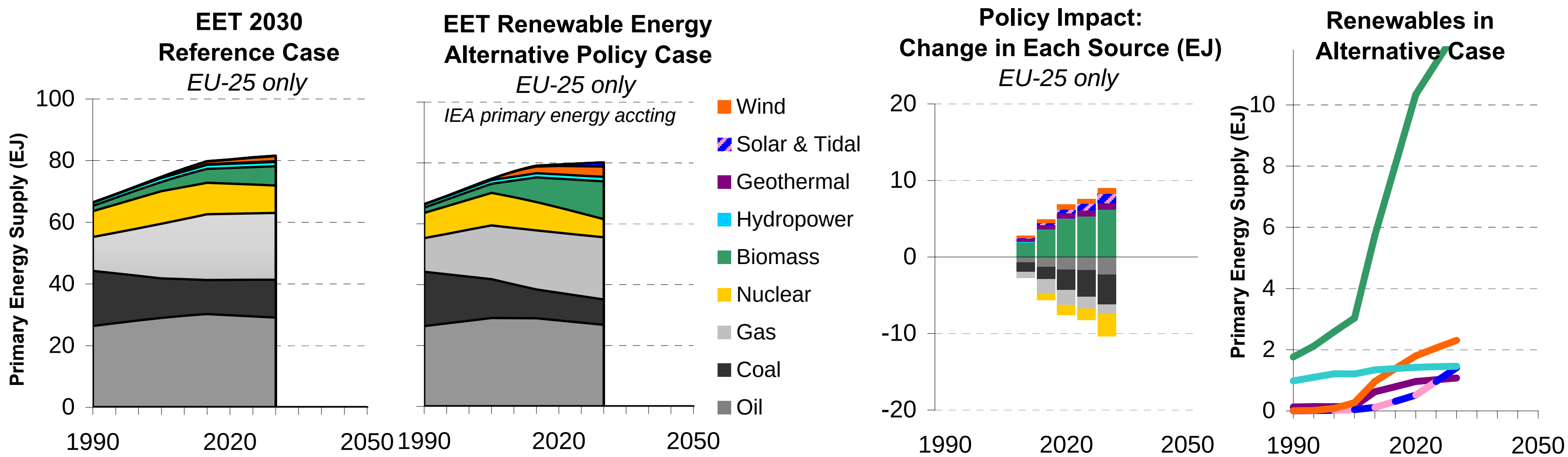
Model description PRIMES is a general equilibrium economic model describing the energy sector of the European Union. After explicitly characterizing available energy resources and conversion technologies, it assumes that energy producers and consumers are primarily sensitive to price. The model gives separate treatment to sources of energy supply, the conversion technologies, and end-uses, which are analyzed in three different sub-modules.

Key observations on the role of renewables in this scenario

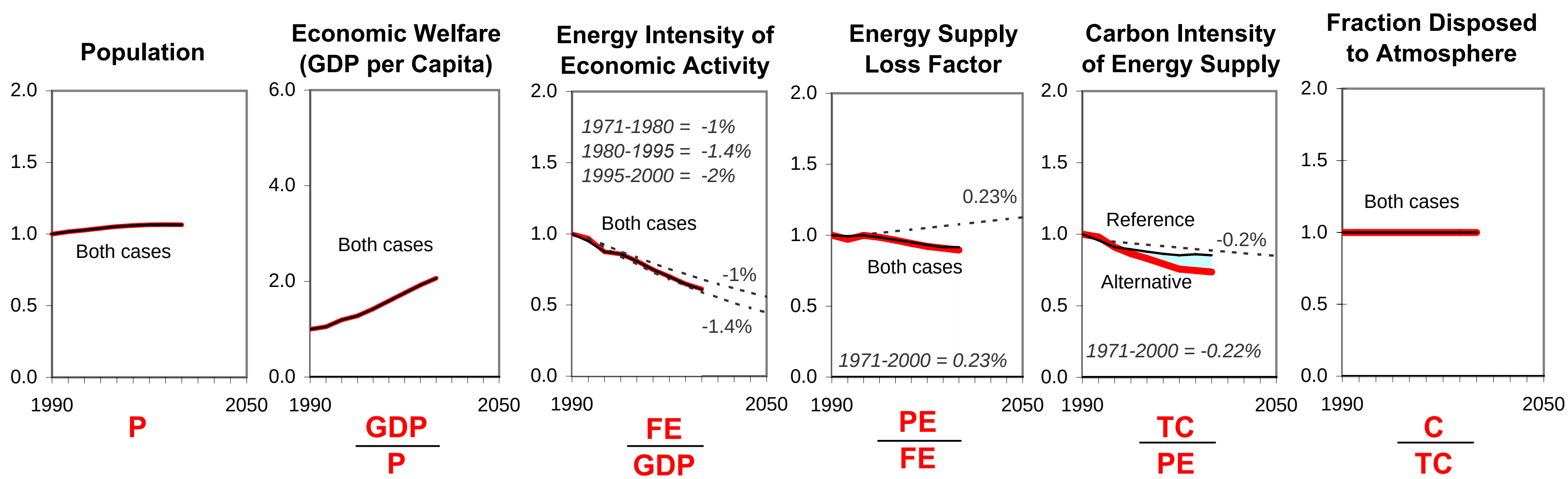
Biomass use dominates with the fastest growth rate, quadrupling from 2005 to 2030 (instead of doubling in the reference case). The contribution from wind also increases, but the growth rate slows after 2015, and its contribution remains a small fraction of the energy mix. The policy intervention also stimulates growth in geothermal, and solar takes off after 2020. The additional renewable energy drives nearly 15% of the expected fossil fuel and nuclear power out of the energy mix, and this effect - the only impact of the policy intervention - is captured in the dashboard pane for carbon intensity.

Note The primary energy profile data is for EU-25 only, and the vertical scale is 10% of the global profiles generated for other scenarios. A small quantity of imported electricity is attributed to nuclear power as a simplifying assumption, and this has the effect of increasing nuclear power by 1-2%.

EU-25 Primary Energy Supply Profile



Key Driver Metrics for EU-25, Indexed to 1990 = 1



II.2 Scenario on Energy Efficiency, European Energy and Transport (2006)

Reference case How could the European Union (EU-25) energy system evolve if only the current set of policies persist through 2030?

Alternative case How could the European Union (EU-25) energy system evolve if the policies outlined in the Energy Efficiency Green Paper of 2005 were implemented?

Scenario narrative This baseline (*EET Trends to 2030, update 2005*) assumes that present policies will be implemented, though without assuming that specific renewable energy targets will be met. The scenario does reflect the decision of some member countries to phase out nuclear power. The price of crude oil is presumed to exceed US$50 (in 2005 dollars) through 2030, economic growth persists at 2%, and population growth for the region is low. While the Energy Efficiency Case shares all of these features, it also reflects the implementation of measures described in the Energy Efficiency Green Paper of 2005, which stated that with existing technology, it is possible to save around 20% of our energy consumption by an increase in energy efficiency on a cost effective basis. The scenario explores the potential impact of directives on building performance, end-use energy efficiency, energy services, energy efficiency labeling, eco-design and other measures that could help to exploit large parts of this potential when fully implemented.

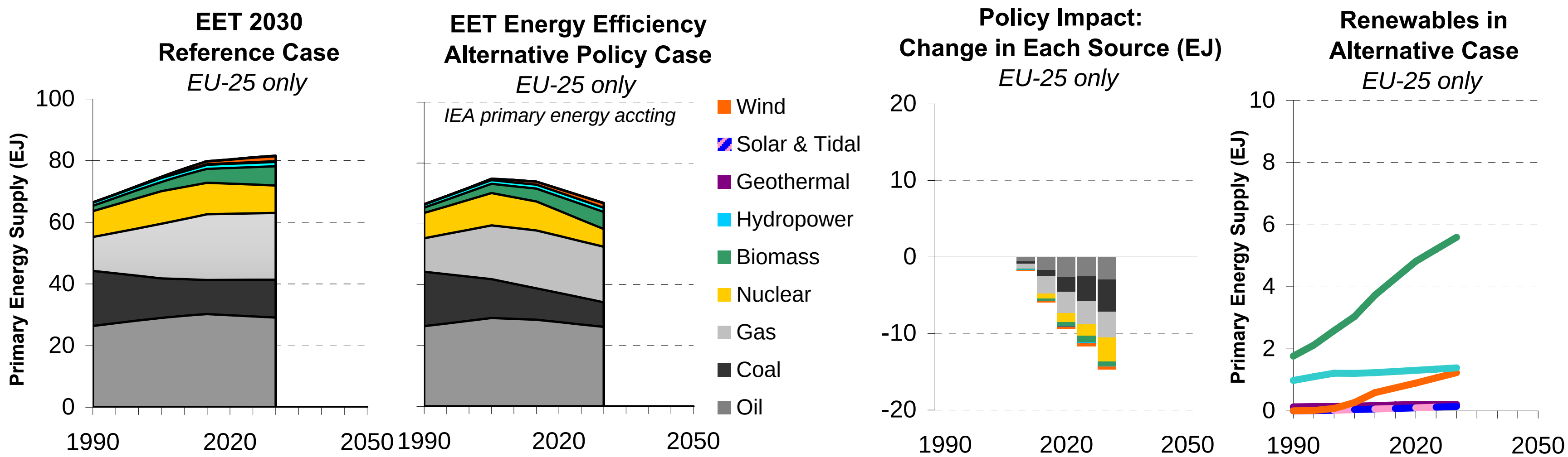
Model description PRIMES is a general equilibrium economic model describing the energy sector of the European Union. After explicitly characterizing available energy resources and conversion technologies, it assumes that energy producers and consumers are primarily sensitive to price. The model gives separate treatment to sources of energy supply, the conversion technologies, and end-uses, which are analyzed in three different sub-modules.

Key observations on the role of renewables in this scenario

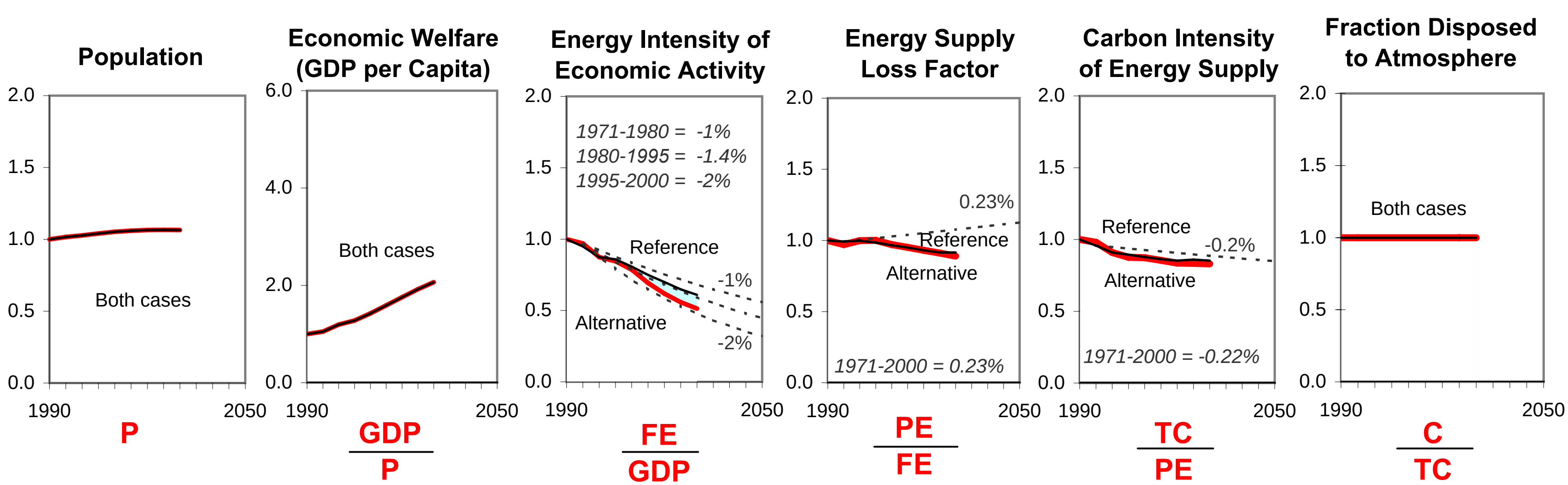
Though efficiency investments reduce the amount of energy needed from all sources in the future, those savings are not reinvested in additional renewable energy capacity in this case, so observations about renewables reflect the reference case assumptions. Biomass use dominates with the fastest growth rate, doubling from 2005 to 2030. Wind also experiences strong growth, especially compared to solar, which remains a fringe technology in the mix. The reference case assumes a strikingly optimistic departure from the worldwide trend of declining supply efficiency driven primarily by electrification (see dashboard pane for energy supply loss factor). The impact of the policy interventions to promote efficiency appears not to improve supply efficiency any further, and instead, their effects are apparent in the dashboard pane for energy intensity.

Note The primary energy profile data is for EU-25 only, and the vertical scale is 10% of the global profiles generated for other scenarios. A small quantity of imported electricity is attributed to nuclear power as a simplifying assumption, and this has the effect of increasing nuclear power by 1-2%.

EU-25 Primary Energy Supply Profile



Key Driver Metrics for EU-25, Indexed to 1990 = 1



II.3 Combined High Renewables & Efficiency, European Energy & Transport (2006)

Reference case How could the European Union (EU-25) energy system evolve if only the current set of policies persist through 2030?

Alternative case What could be the effect on the EU-25 energy system of the renewable energy target (12% in 2010 and 20% in 2020) combined with the energy efficiency measures explored in the High Efficiency case?

Scenario narrative This baseline (*EET Trends to 2030, update 2005*) assumes that present policies will be implemented, though without assuming that specific renewable energy targets will be met. The scenario does reflect the decision of some member countries to phase out nuclear power. The price of crude oil is presumed to exceed US$50 (in 2005 dollars) through 2030, economic growth persists at 2%, and population growth for the region is low.

Policy measures explored in both the High Efficiency and the High Renewables case are combined in this scenario, by applying both to the future described in the baseline case. Therefore, in addition to imposing the renewable energy targets of 12% in 2010 and 20% in 2020, the EU-25 also successfully executes directives on building performance, end-use energy efficiency, energy services, energy efficiency labeling, eco-design and other measures.

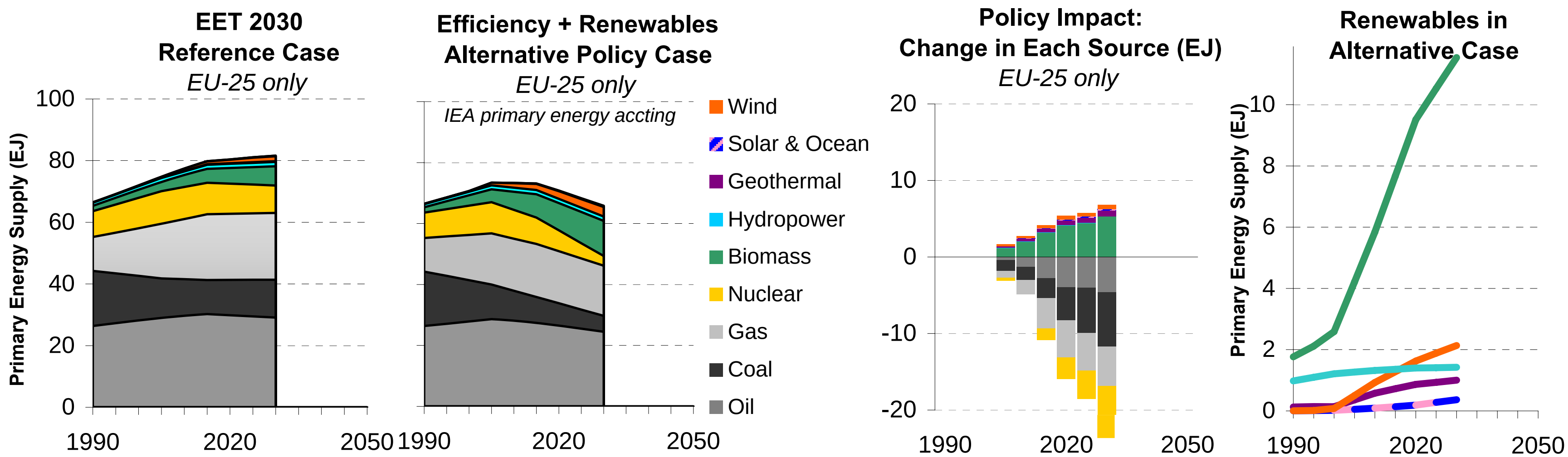
Model description PRIMES is a general equilibrium economic model describing the energy sector of the European Union. After explicitly characterizing available energy resources and conversion technologies, it assumes that energy producers and consumers are primarily sensitive to price. The model gives separate treatment to sources of energy supply, the conversion technologies, and end-uses, which are analyzed in three different sub-modules.

Key observations on the role of renewables in this scenario

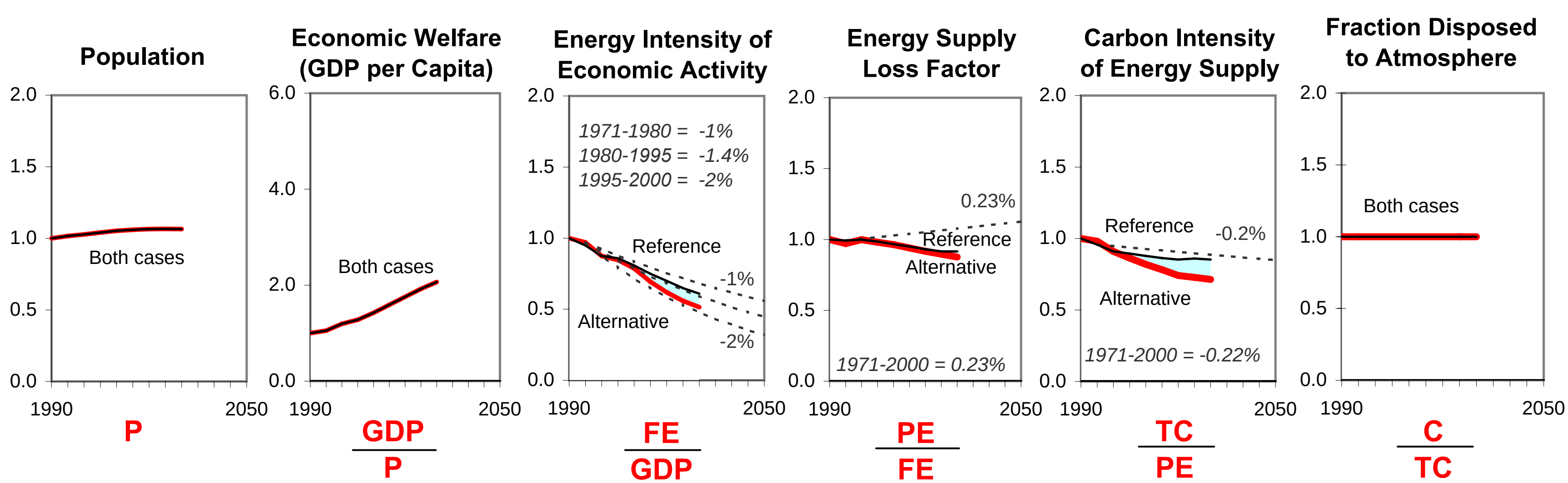
The combination of efficiency and renewables drives nearly twice as much fossil and nuclear power out of the baseline energy portfolio than using either strategy alone. Biomass use is most stimulated by the policies, and the additional efficiency available at lower cost benefits relaxes demand for solar power under this scenario. Overall, non-biomass renewables would still constitute a very small portion of the primary energy mix for the EU-25 in 2030. The strikingly optimistic assumption about supply efficiency (see energy supply loss factor pane) persists in all three scenarios in the EET set, and the dashboard of key drivers disaggregates the impact of the efficiency and renewables policies separately (energy intensity pane and carbon intensity pane).

Note The primary energy profile data is for EU-25 only, and the vertical scale is 10% of the global profiles generated for other scenarios. A small quantity of imported electricity is attributed to nuclear power as a simplifying assumption, and this has the effect of increasing nuclear power by 1-2%.

EU-25 Primary Energy Supply Profile



Key Driver Metrics for EU-25, Indexed 1990 = 1



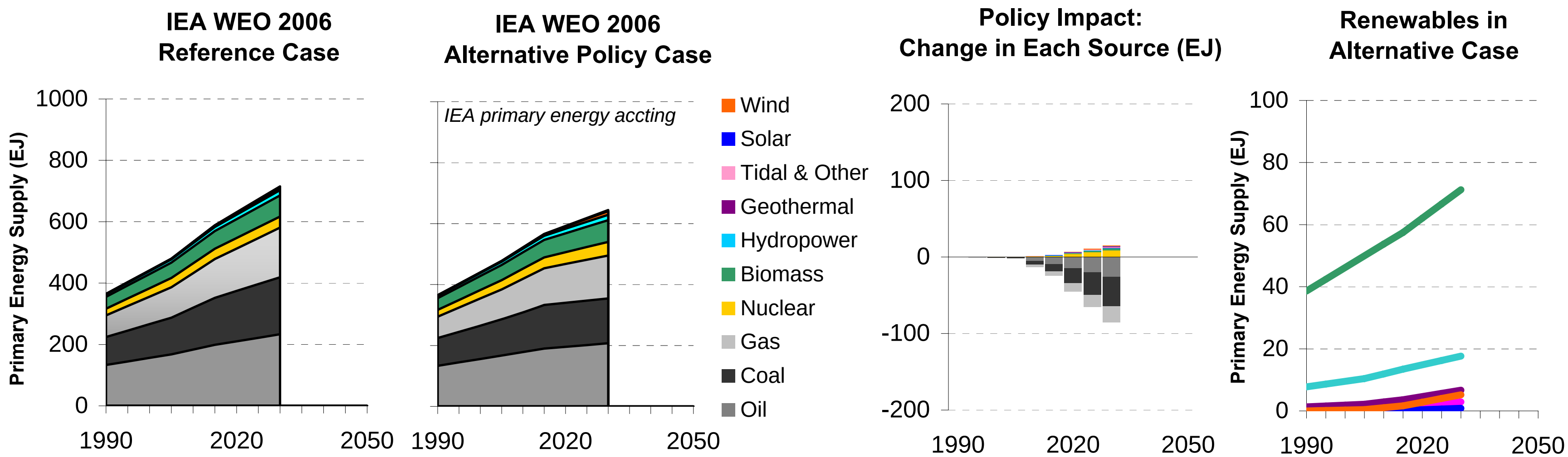
II.4 World Energy Outlook 2006 & Alternative Policy Case, International Energy Agency (2006)

Reference case	How could the global energy system evolve if governments maintain policies currently in place?
Alternative case	How could the global energy system evolve if countries adopted and implemented policies related to energy security and energy-related carbon emissions presently under consideration?
Scenario narrative	With an existing policy context held constant over time in the baseline, the future tends to reflect trends of the past. However, this Reference case diverges from prevailing trends in some important dimensions: slowing population growth, a higher rate of economic growth than the recent past, and higher oil prices. The minimum oil price over the 25 year Reference case is $47 per barrel, yet under the present policy regimes (and even those under consideration), renewable energy remains a minor contributor to the global energy supply in 2030. The basic assumptions about economic growth and population as well as oil and gas import prices are the same in the Alternative Policy case as the Reference case. However, the Alternative Policy case applies additional policies related to energy security and energy-related emissions that were under consideration by governments in 2006. These policies are characterized in a database of 1,400 measures, and most of them pertain to energy efficiency. The benefits of greater energy security and avoided environmental damages realized in this scenario are achieved at a lower total level of investment than required in the Reference case.
Model description	World Energy Model (WEM) projects future energy use based on exogenous assumptions about population, economic growth, and energy prices applied to thousands of parameters for energy demand highly correlated with historical trends. Renewable energy use is influenced by a calculation of each technology's realisable potential in each of twenty regions, the assignment of technological learning rates, and dynamic cost resource curves. These concepts and other details for the many submodules of this model are described in supplemental documentation to the WEO: http://www.worldenergyoutlook.org/annex_c.pdf.

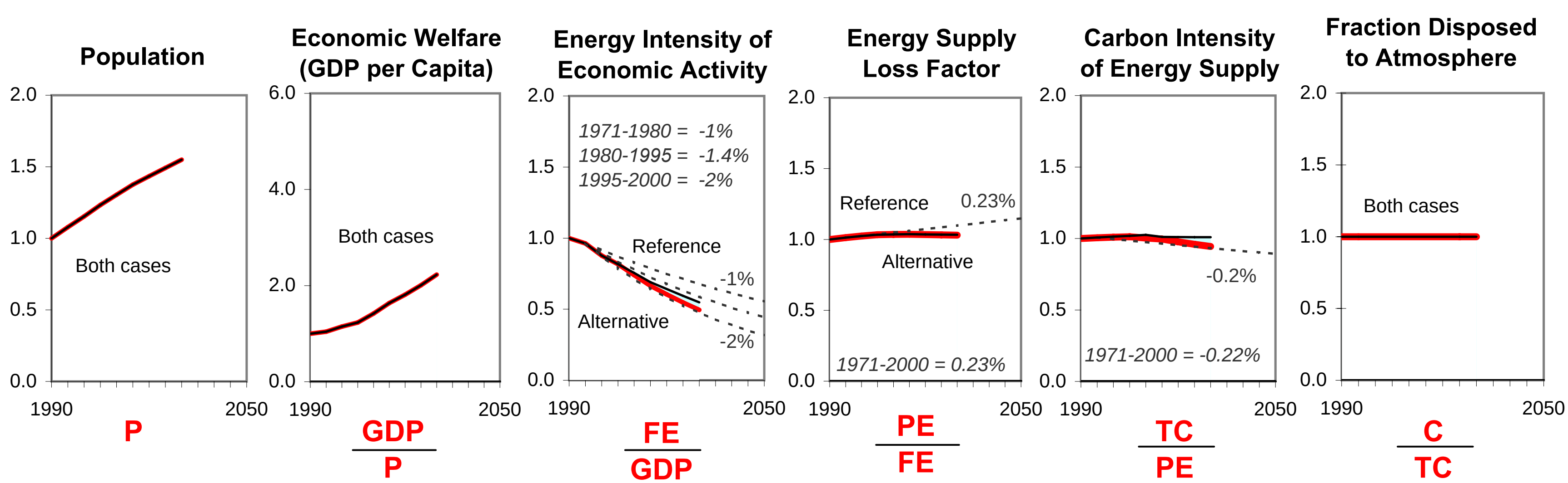
Key Observations on the Role of Renewables in this Scenario

Aside from biomass, the contribution of renewable energy sources is extremely limited. The assumed capacity factor for wind (25 to 32%) is low and the cost range is large (5 to 7.5 cents/kwh). Perhaps more importantly, the nuclear costs are relatively low (4.8 to 5.8 cents.kWh) by comparison. Wind is the only renewable energy source for which cost ranges are disclosed in the report. The WEM model indicates that the policies currently under consideration (Alternative Policy Case) would primarily motivate efficiency and conservation along with construction of additional nuclear power plants.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



II.5 World Energy Outlook 2006 & Beyond Alternative Policy Scenario, IEA (2006)

Reference case How could the global energy system evolve if governments maintain policies currently in place?

Alternative case How could the global energy system evolve if, in addition to those measures adopted in the Alternative Policy Scenario, more measures were taken to assure that carbon emissions in 2030 were not higher than in 2004?

Scenario narrative With an existing policy context held constant over time in the baseline, the future tends to reflect trends of the past. However, this Reference case diverges from prevailing trends in some important dimensions: slowing population growth, a higher rate of economic growth than the recent past, and higher oil prices. The minimum oil price over the 25 year Reference case is $47 per barrel, yet under the present policy regimes (and even those under consideration), renewable energy remains a minor contributor to the global energy supply in 2030.

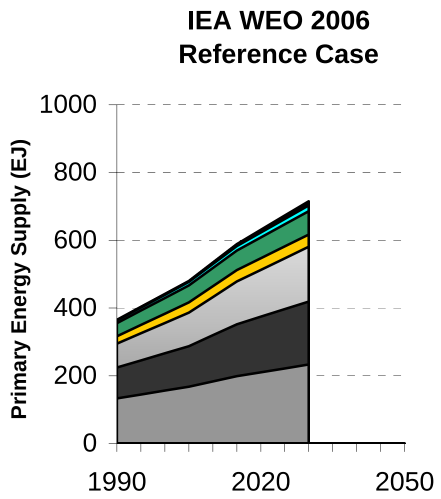
The basic assumptions about economic growth and population as well as oil and gas import prices are the same in the Alternative Policy case as the Reference case. However, the Beyond Alternative Policy Scenario limits carbon emissions to 2004 levels in 2030, which is 8 GtCO2 below the result in the Alternative Policy Scenario. BAPS is not a backcasting experiment. Instead, it is the result of the Alternative Policy Case and an additional set of specific measures each presumed to deliver 1 GtCO2 of mitigation similar in style to the Pacala and Socolow "stabilization wedges."

Model description World Energy Model (WEM) projects future energy use based on exogenous assumptions about population, economic growth, and energy prices applied to thousands of parameters for energy demand highly correlated with historical trends. Renewable energy use is influenced by a calculation of each technology's realisable potential in each of twenty regions, the assignment of technological learning rates, and dynamic cost resource curves. These concepts and other details for the many submodules of this model are described in supplemental documentation to the WEO: http://www.worldenergyoutlook.org/annex_c.pdf.

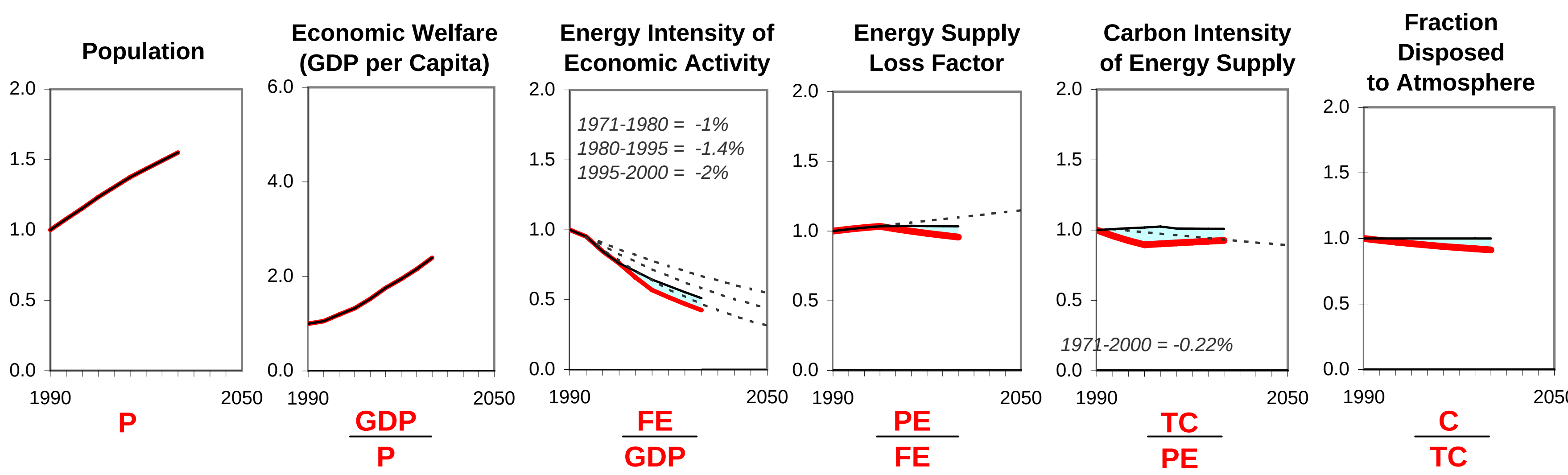
Key Observations on the Role of Renewables in this Scenario

Primary energy data was not available for this scenario. Also, no data for specfic renewable energy technologies were reported. Therefore, the analysis of this scenario is limited to the dashboard decomposition of key drivers. In comparison with the Alternative Policy Scenario for this same study (see Appendix II.4 IEA WEO 2006), the impact of the additional measures is striking. BAPS draws 2.5 GtCO2 of additional mitigation from carbon sequestration and 2.5 GtCO2 of additional mitigation from efficiency. By comparison, 1 GtCO2 comes from additional renewable energy use, half of which is hydropower. In 2030, 32% of global electricity use is attributed to renewable energy sources.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



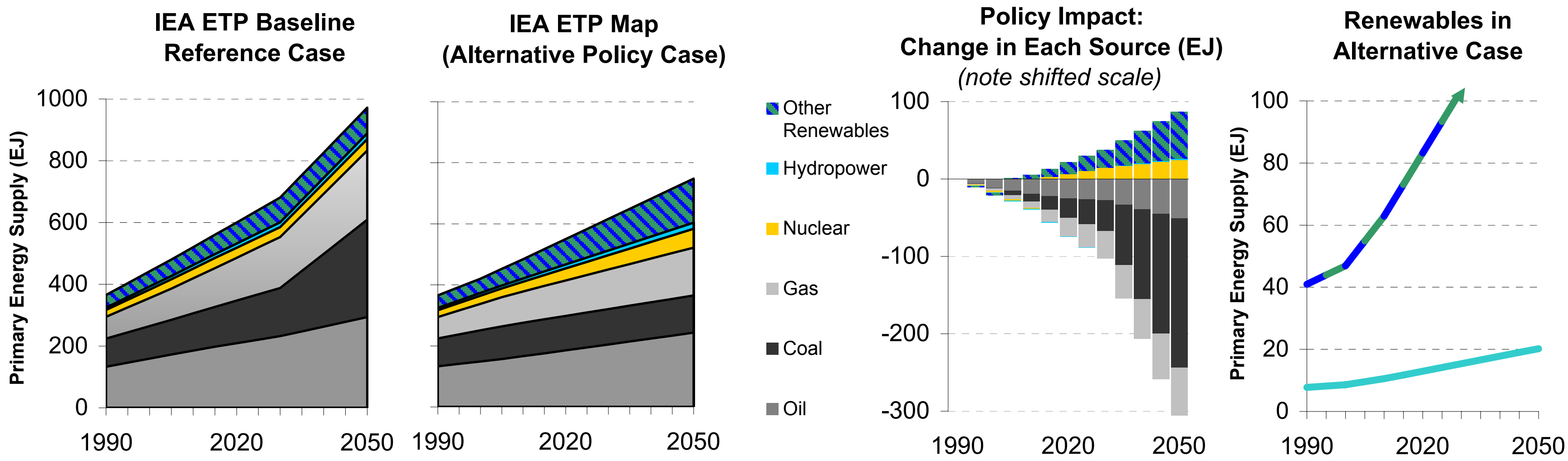
II.6 MAP Scenario, Energy Technology Perspectives, IEA (2006)

Reference Case	How could the global energy system evolve if governments maintain policies currently in place through 2030, and this projection is extended thtough 2050?
Alternative Case	What is the potential of energy technologies and best practices aimed at reducing energy demand and emissions and diversifying energy sources?
Scenario narrative	The baseline for this study is based on IEA's World Energy Outlook 2005, which tends to project trends of the past into the future by holding constant the existing policy context. However, this Reference case diverges from prevailing trends in some important dimensions: slowing population growth, a higher rate of economic growth than the recent past, and minimum oil prices over the 25 year scenario horizon of $47 per barrel. The Map scenario explores the potential for a more sustainble energy path by assuming strong energy efficiency gains in transport, industry, and buildings as well as fuel switching to nuclear power, renewables, natural gas, and coal with carbon sequestration. This scenario also calls for increased use of biofuels for road transport. Five main types of policy interventions drive these improvements: increased support for energy technology research and development, demonstration and deployment programs, carbon dioxide mitigation incentives, and policy instruments to overcome non-financial barriers to commercialization (e.g. standards, labeling, public education, auditing.)
Model description	The reference case is based on the IEA World Energy Outlook 2005, which is generated by the World Energy Model (IEA). (See scenario profile II.4 for a description.) The Energy Technology Perspectives model is used to generate the alternative cases in this study. ETP is a global 15-region model that uses cost-optimization to identify least-cost mixes of energy technologies and fuels to meet energy service demand, given constraints like the availability of natural resources. The model's detailed representation of technology options includes about 1,000 individual technologies. In this study, the ETP model is supplemented with detailed demand-side models for major end-uses in the industry, buildings, and transport sectors. These models were developed to assess the effects of policies that do not primarily act on price. These demand-side models explicitly take into account capital-stock turnover and have been used to model the impact of new technologies as they penetrate the market over time.

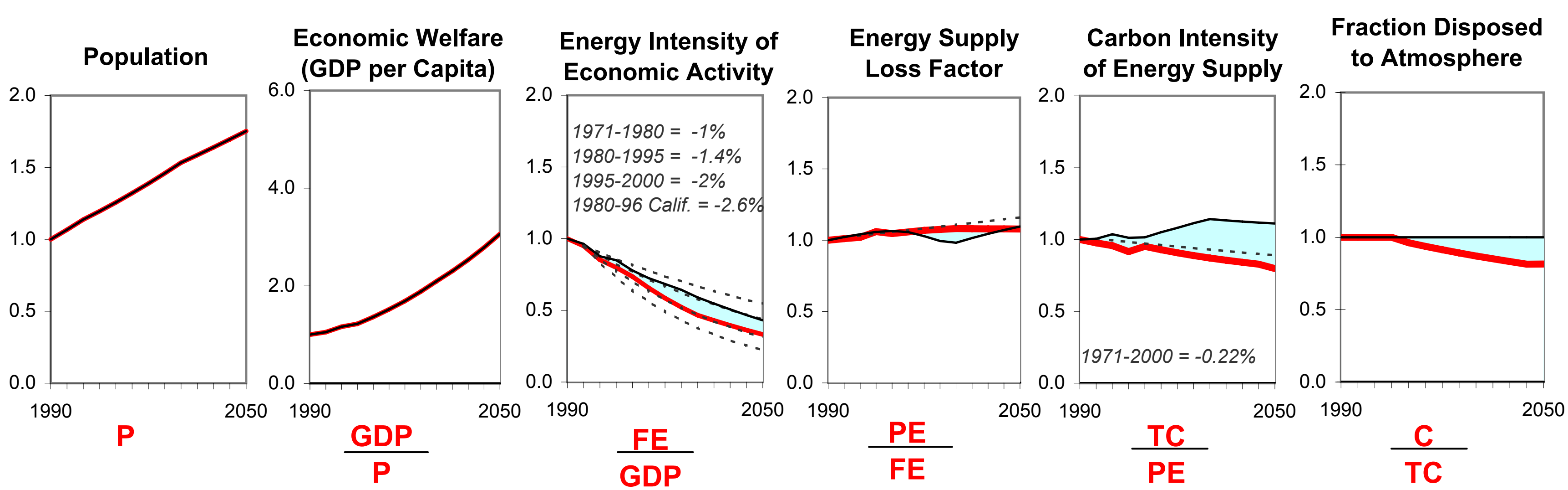
Key Observations on the Role of Renewables in this Scenario

This report uses a baseline that extends the IEA's World Energy Outlook 2005 beyond 2030 to 2050. However, the primary energy data for the reference case indicates a sharp departure from the published trends through 2030 with an aggressive increase in the quantity of coal consumed. Thus, the improvements in the Map scenario barely regain the market share for renewables and overcome the aggressive acceleration of coal consumption in the latter part of the baseline. With the exception of hydropower, data for renewable energy sources are reported as a combined quantity. Efficiency improvements in the Map scenario are significant, reducing demand by nearly 25%. The Map scenario implies that nearly 20% of all carbon dioxide generated in the energy system will be sequestered each year by 2045.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



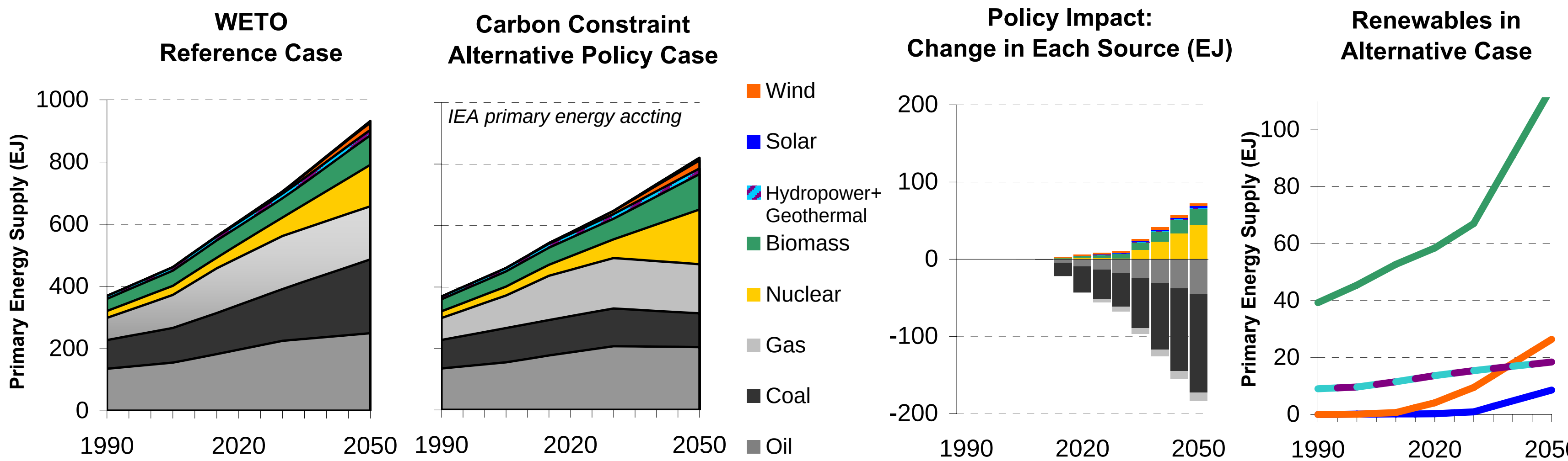
II.7 World Energy Technology Outlook with a Carbon Constraint, European Commission (2006)

Reference case	What could be the evolution of the global energy system if existing economic and technological trends continue?
Alternative case	What would be the effect of a policy to impose a cost of carbon starting in 2020 that would keep worldwide emissions on a trajectory to stabilize at 500ppmv by 2100?
Scenario narrative	In the Reference case, population reaches 8.9 billion and global GDP quadruples over 2005 levels by 2050. Existing economic and technology trends persist. However, a "minimum" level of climate policy is represented by incorporating a carbon cost to fossil-fuel based technologies in industrialized countries, and introducing lower carbon costs to developing countries later. Even still, the results suggest carbon dioxide concentrations exceeding 1000 ppmv by 2100. The Carbon Constraint scenario imposes a rising cost of carbon emissions beginning in 2020, driving emissions down to a level 25% above the 1990 benchmark by 2050. In addition, non-fossil technologies decline in cost to such an extent that carbon sequestration is not cost effective. EU-25 emissions decline by approximately 10% per decade, reaching half of 1990 levels by 2050. Global annual emissions are held constant when industrialzed countries reach a carbon cost of 25 Euros/mtCO2 (or 7euros/mtC), and when developing countries reach this same carbon cost almost a decade later, worldwide emissions begin to decline. If this trajectory is maintained, accumulation of carbon dioxide in the atmosphere could be held to 500ppmv in 2100.
Model description	POLES is a partial equilibrium model that uses a dynamic recursive process to simulate energy development over time. POLES determines the profile of a future energy system using a framework of permanent competition between technologies with dynamically changing attributes. A TECHPOL technology database contains expected cost and performance data for a dozen conventional technologies, eight renewable energy technologies, ten hydrogen-based technologies, and nine types of technology that would improve the efficiency of end-use energy service delivery. The technology cost curves are decline over time, and appear to be independent of cumulative installed capacity. This study included a supplemental optimization analysis using the finance technique of mean-variance portfolio optimization to incorporate dimensions of risk and liability into the determination of the Reference case. Finally, although the model does not calculate the macro-economic impacts of mitigation scenarios, it does produce economic assessments based on the costs of implementation of new technologies.

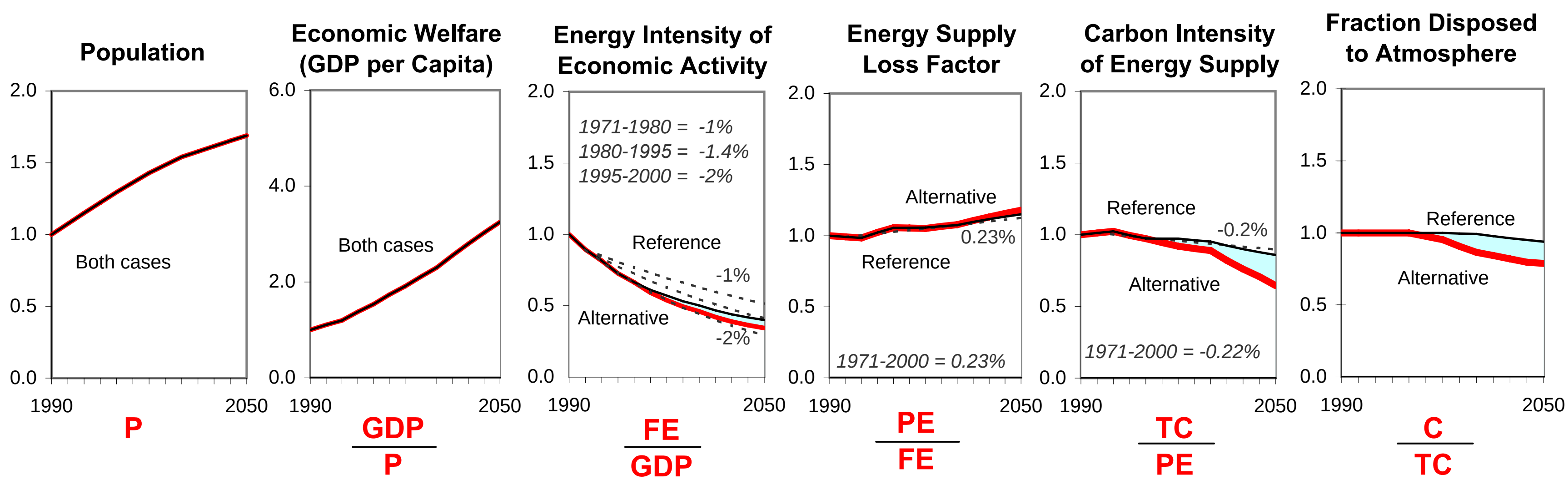
Key observations on the role of renewables in this scenario

The POLES model indicates that a carbon constraint would induce deployment of carbon sequestration and more nuclear power, having only a very modest effect on the contribution of renewable energy technologies to the total energy portfolio. By 2050, renewables and nuclear each provides more than 20% of the total demand; renewable sources provide 30% of electricity generation and nuclear electricity nearly 40%. Despite limiting growth in coal consumption by adding nuclear power capacity and some renewable generating technologies, the scale of coal usage at 1990 still persists via the large-scale deployment of carbon capture and sequestration.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



II.8 Towards a Hydrogen Economy, World Energy Technology Outlook, EU Commission (2006)

Reference Case: What could be the evolution of the global energy system if existing economic and technological trends continue?

Alternative Case: Assuming several technological breakthroughs, how could the world energy system evolve toward a hydrogen economy?

Scenario narrative: In the Reference case, population reaches 8.9 billion and global GDP quadruples from 2005 to 2050. Existing economic and technology trends persist. However, a "minimum" level of climate policy is represented by adding a carbon cost to fossil-fuel based technologies in industrialized countries, and introducing lower carbon costs to developing countries later. Even still, the results suggest CO2 concentrations would exceed 1000 ppmv by 2100.

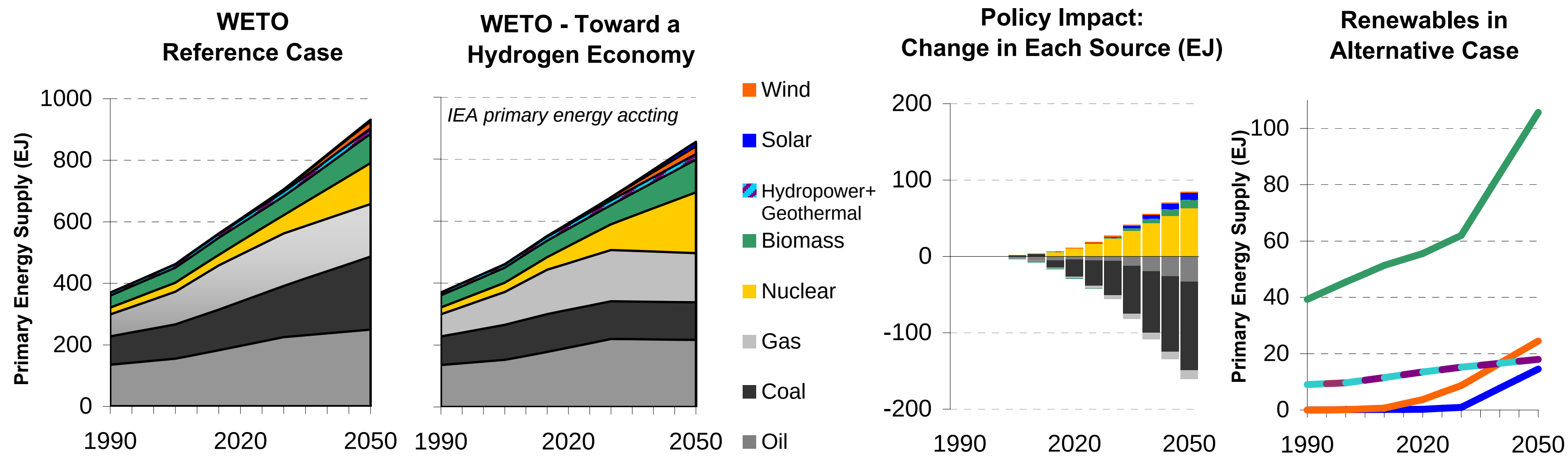
The hydrogen scenario considers technological and socio-economic pathways that illustrate possible ways to incorporate hydrogen into the world energy system. It implies a number of technology breakthroughs to make hydrogen technologies, mainly on the end-use side, more cost effective. The origins of the hydrogen are presumed to be steam reforming of natural gas; gasification of coal; gasification of biomass; electrolysis of water and thermolysis. Because the fossil fuel sources would be likely to dominate in the early period of the hypothetical transition, this future also depends on the successful development and deployment of carbon capture and sequestration. This scenario explores the impact of achieving specific cost ranges for breakthrough technologies needed in either a centralized fossil-based pathway or an electricity-based hydrogen pathway.

Model description: POLES is a partial equilibrium model that uses a dynamic recursive process to simulate energy development over time. POLES determines the profile of a future energy system using a framework of permanent competition between technologies with dynamically changing attributes. A TECHPOL technology database contains expected cost and performance data for a dozen conventional technologies, eight renewable energy technologies, ten hydrogen-based technologies, and nine types of technology that would improve the efficiency of end-use energy service delivery. The technology cost curves are decline over time, and appear to be independent of cumulative installed capacity. This study included a supplemental optimization analysis using the finance technique of mean-variance portfolio optimization to incorporate dimensions of risk and liability into the determination of the Reference case. Finally, although the model does not calculate the macro-economic impacts of mitigation scenarios, it does produce economic assessments based on the costs of implementation of new technologies.

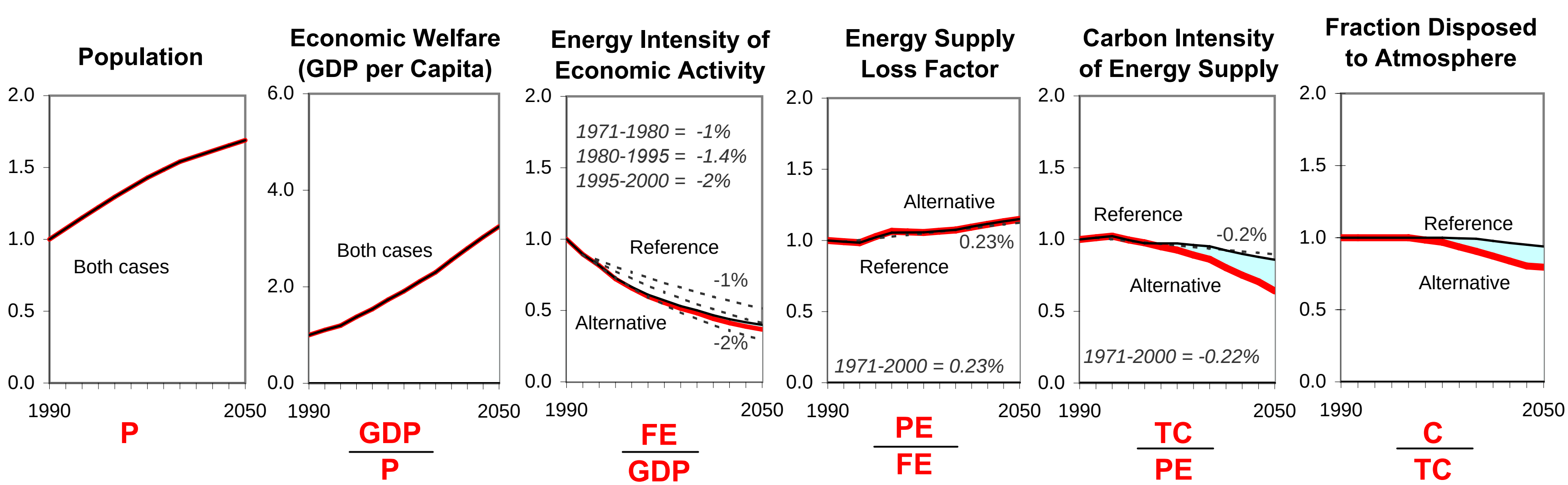
Key Observations on the Role of Renewables in this Scenario

The transition towards a hydrogen economy pathway described in this scenario ultimately relies heavily on nuclear power and fossil fuel paired with carbon sequestration. For all the expense of hydrogen technologies and carbon sequestration, improvements energy efficiency appear understated. Because solar plays an absolutely negligible role in the reference outlook, the hydrogen technology breakthroughs do have positive implications for solar and biomass, but growth in the wind industry is hardly affected at all. The solar industry appears almost dormant until 2030, at which point growth in the use of modern biofuels also increases dramatically.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



II.9 Energy [r]evolution Scenario, EREC / Greenpeace (2007)

Reference Case: How would the energy system evolve if present (2004) policies persist?

Alternative Case: How could the energy system evolve if opportunities to improve efficiency and switch to renewable energy were fully exploited?

Scenario narrative: The reference case is the IEA World Energy Outlook 2004, extended out to 2050.

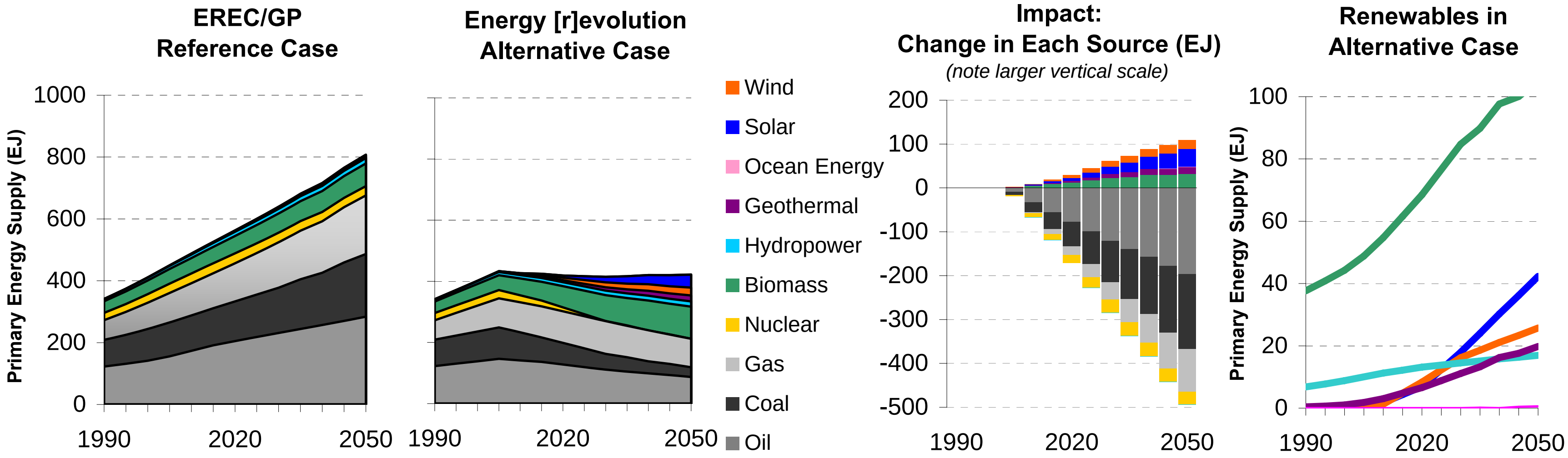
Population and economic growth projections are the same in the reference and alternative ([r]evolution) case. Energy is further decoupled from economic growth by accelerating the decline in energy intensity of economic activity. This is primarily achieved through policy changes that promote investments in energy efficiency. The [r]evolution scenario calls for a phase out of nuclear power, and it does not include any use of carbon sequestration technology.

Model description: The IEA World Energy Outlook 2004 is generated by the World Energy Model. (See description in II.4.) This study did not use WEM to generate the [r]evolution scenario, but rather used a simulation model called MESAP/PlaNet to modify specific assumptions and revise its results. Documentation on this model was not published with the report. However, the text describes a process of using cost estimates and assumptions about technical potential to estimate the quantity of primary energy use that could be avoided (or provided) by a series of efficiency measures (or renewable energy technologies) in each region. These quantities could then be used to modify the primary energy profile of the IEA WEO 2004.

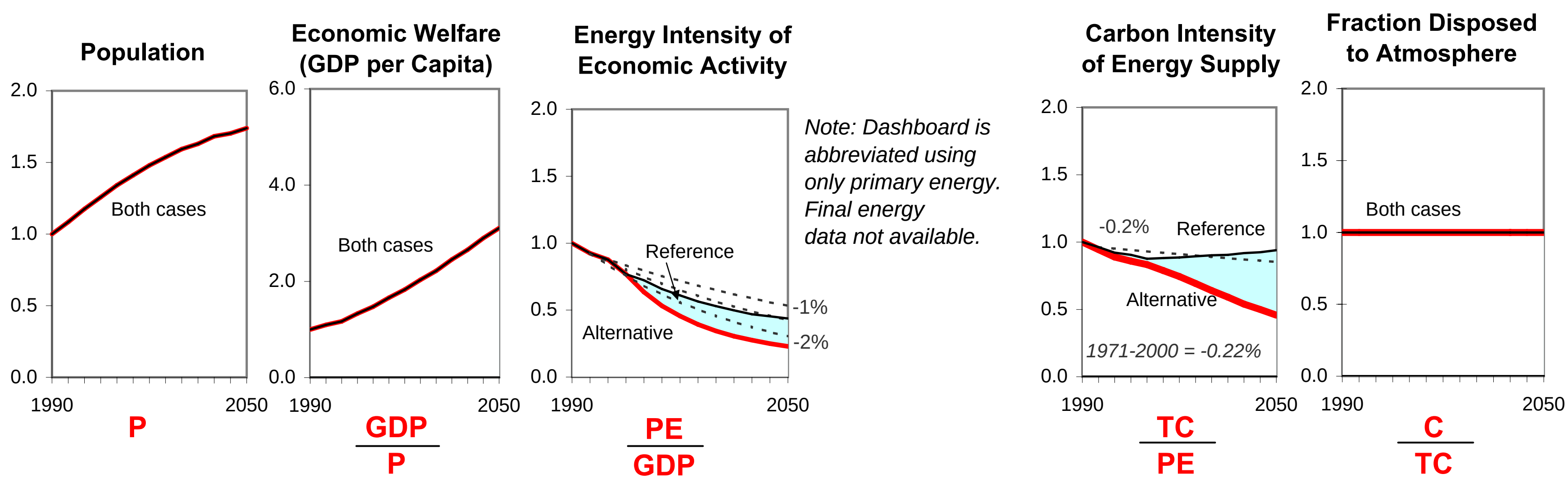
Key Observations on the Role of Renewables in this Scenario

Investments in efficiency have an effect on the primary energy profile that is four times larger than the contribution of new renewable energy. The challenge of achieving this scale of impact is indicated by the sustained improvements to primary energy intensity of economic activity in the [r]evolution scenario, which exceed the highest rates of improvement observed at the global level in the last three decades.Because the expectations for wind, solar, and geothermal energy are negligible in the reference case, the [r]evolution scenario does show remarkable increases in the capacity of each starting in 2010. However, the growth rates are only slightly more aggressive than other scenarios reviewed for this report. Among the renewable energy technologies, solar power has the most aggressive growth profile, which declines from an annual rate of 23% in 2010 to 3% in 2050.

Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



II.10 A2, IPCC Special Report on Emissions Scenarios (2000)

Reference Case: How might the global energy system evolve if population continuously increases while economic activity is regionally fragmented and technological developments progress relatively slowly?

Alternative Case:

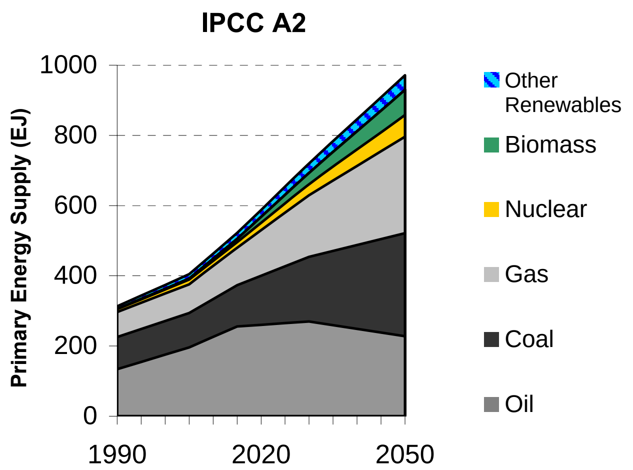
Scenario narrative: The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

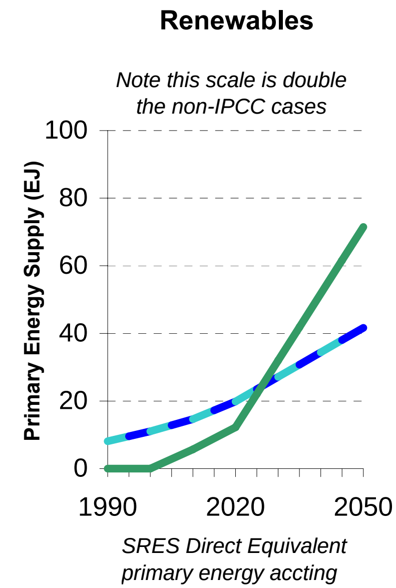
Model description: In the ASF model, balancing the supply and demand for energy is achieved ultimately by adjusting energy prices. Energy prices differ by region to reflect regional market conditions, and by type of energy to reflect supply constraints, conversion costs, and the value of the energy to end users. ASF estimates the supply-demand balance by an iterative search technique to determine supply prices.

Key Observations on the Role of Renewables in this Scenario

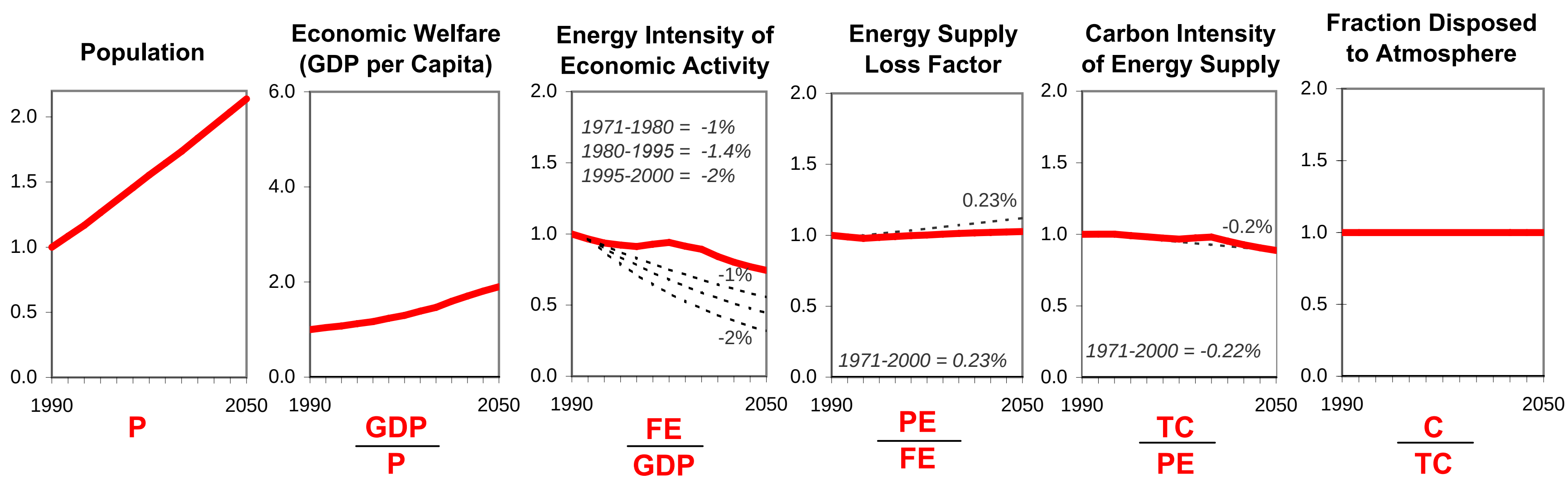
Renewable energy technologies play a negligible role in the global energy system overall, but the rate of expansion for biomass is still remarkable. The stress on the entire system is aggravated by the surprisingly pessimistic treatment of efficiency in this modeling team's rendition of an A2 future. Efficiency is perhaps the most quintessentially local resource. The ASF model indicates that coal and natural gas are cheaper than efficiency on a scale that is triple the current rates of consumption, which does challenge the imagination - and diminish the relative contribution of renewable energy technologies of any type.

Global Primary Energy Supply Profile





Key Driver Metrics, Indexed to 1990 = 1



II.11 B1, IPCC Special Report on Emissions Scenarios (2000)

Reference Case: How might the global energy system evolve if population growth slows and consumption worldwide is dampened by dematerialization of the economy and rapid adoptation of efficient technologies?

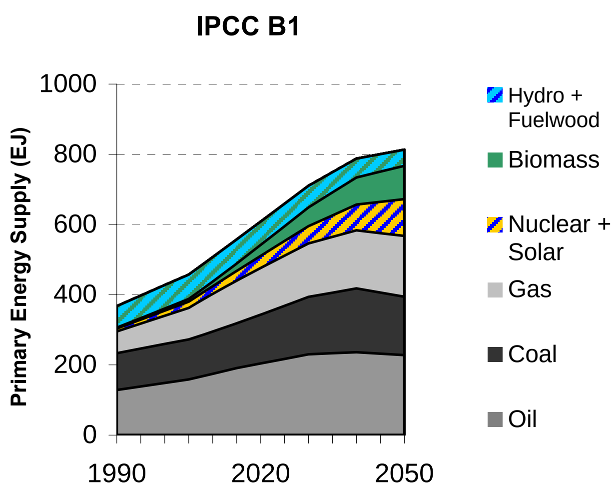
Scenario narrative: The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 sotryline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. (Full description in SRES Section 4.3.3.)

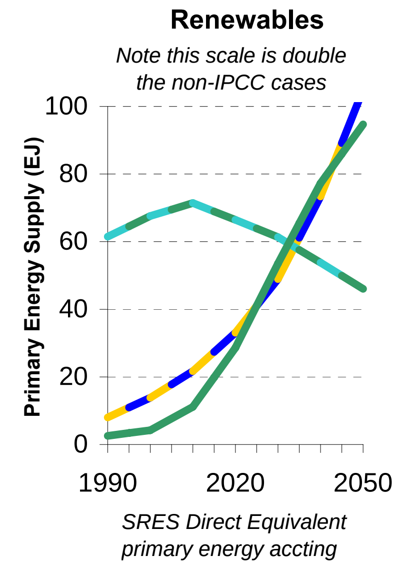
Model description: IMAGE 2.2 is a simulation model that integrates an energy-economics model (TIMER) with other modules that analyze land-use change, air pollution and population welfare over 17 regions. IMAGE has a limited number of energy technology options, and it combines nuclear power with solar and wind when reporting results.

Key Observations on the Role of Renewables in this Scenario

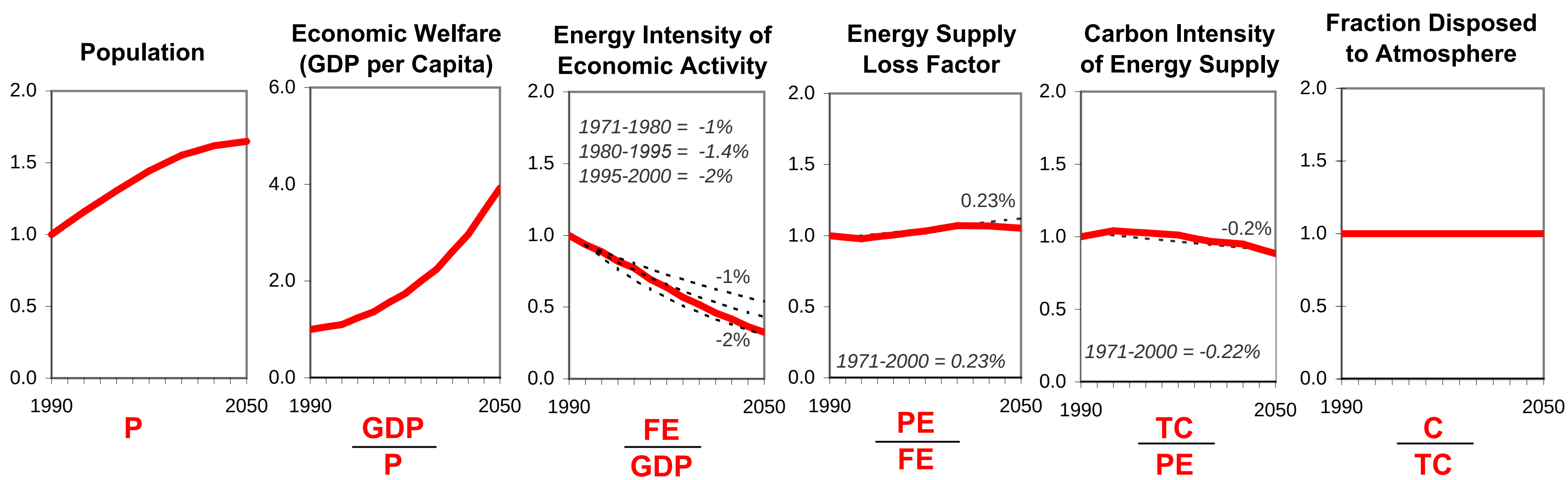
Solar power and biomass are the only two renewable energy resources that are both characterized in this model and experience any growth in this scenario. The component of solar power is merged with nuclear power in the reporting, which challenges the analysis. Nuclear power, solar power, and biomass all experience a surge as production of oil peaks and growth in consumption of coal and natural gas stabilizes.

Global Primary Energy Supply Profile





Key Driver Metrics, Indexed to 1990 = 1



II.12 A1B, IPCC Special Report on Emissions Scenarios (2000)

Reference Case: How might the global energy system evolve in a context of very rapid economic growth, relatively low population growth, rapid technological innovation?

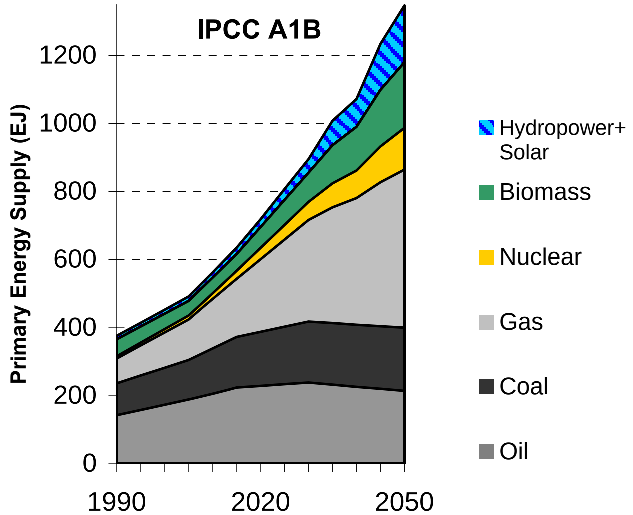
Scenario narrative: The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions (in terms of economic development), capacity building, and increased cultural and social interactions, with substantial reduction in regional differences in per capital income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system. (For full description, see SRES Section 4.3.1.)

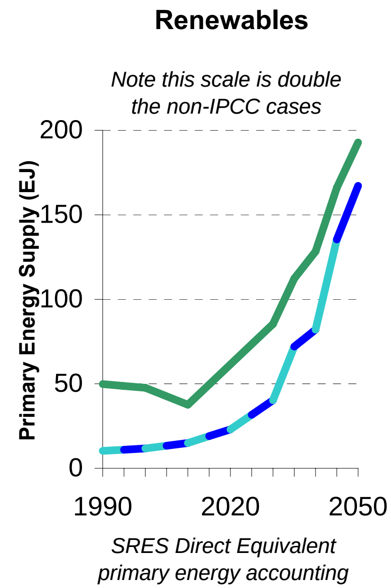
Model description: AIM is a engineering-economics model with a rich level of technology detail specific to the Asia-Pacific region, coupled with a model that characterizes world energy use without such detail. AIM features a "bottom up" technology approach to energy development, with a particular focus on end-uses. It also has a feedback link with a "top down" macroeconomic model to gauge the impact changes in the energy sector have on the rest of the system.

Key Observations on the Role of Renewables in this Scenario

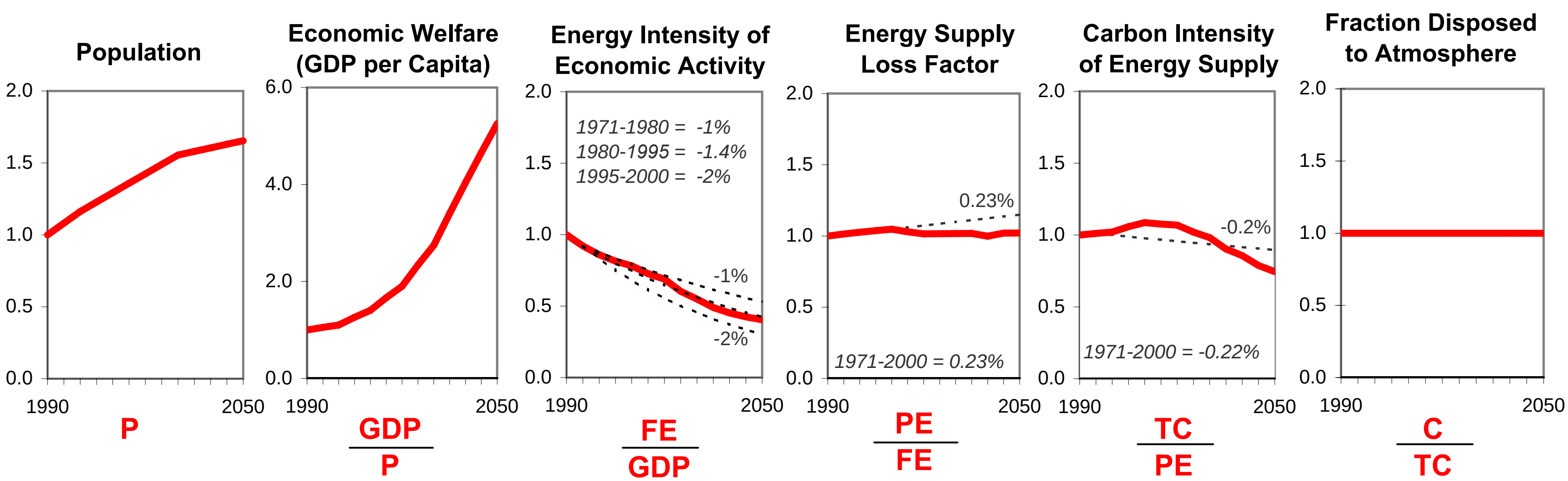
Biomass begins the century in decline because traditional, non-commercial use is in a state of decline. Then modern biofuels launches, and the component of solar and wind (reported in the same category as hydropower) also surge from 2030 to 2050. Note that the scale on the renewables chart is double all others in this sample set. Despite the fact that biomass and solar (with hydro) reach such a scale and attain such a high rate of growth by mid-century, they are still not even able to keep pace with the marginal increase in demand each year under the conditions of this scenario.

Global Primary Energy Supply Profile





Key Driver Metrics, Indexed to 1990 = 1



II.13 Case A, Scenarios to 2050, World Energy Council & IIASA (1998)

***Note:** This scenario profile is not a pair of reference & intervention cases, but instead, it is a comparison of two scenarios with divergent technological development paths in a semilar demographic context.*

Reference Case: How might the global energy system evolve in a future characterized by high economic growth and technological innovation that is neutral toward coal and nuclear power and instead focuses on oil and gas?

Alternative Case: How might the global energy system evolve in a future characterized by high economic growth and technological innovation specifically in nuclear power and large-scale renewables?

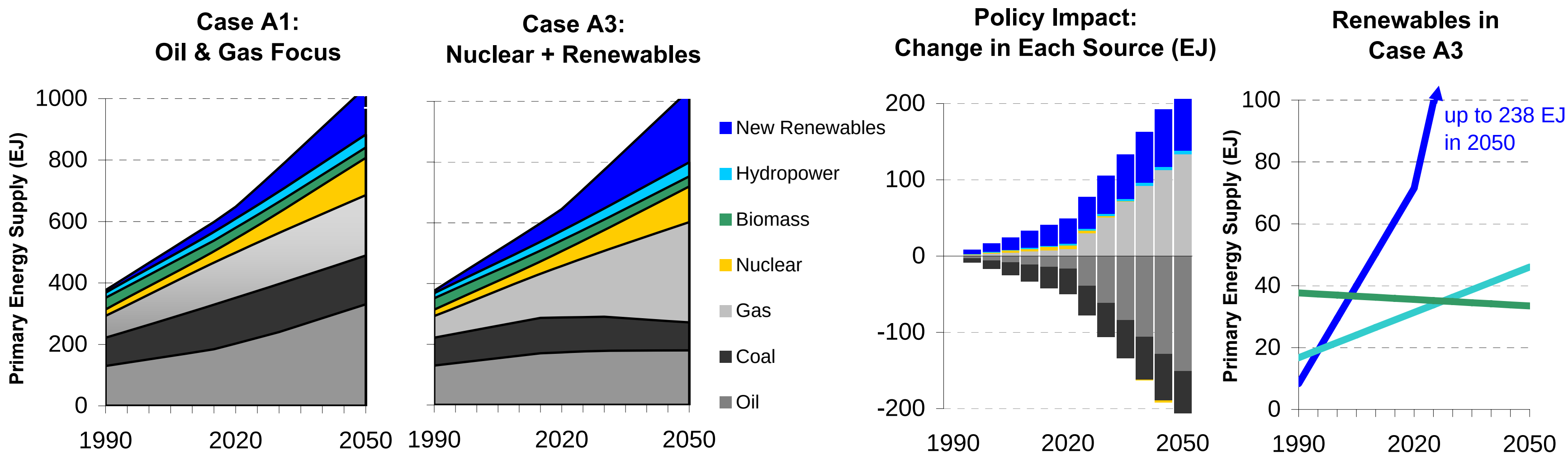
Scenario narrative: The Case A scenarios describe a future with high economic growth, rapidly increasing standards of living, favorable geopolitical conditions, free markets, and rapid technological innovation. The conditions of the A1 and A3 versions are very similar, with the exception of the orientation of technological innovation. This is *not* a "reference + intervention" pair of scenarios, but two different exploratory reference cases with similar demographic and economic underpinnings. Also note that biomass is reported as traditional biomass, which has a long-term declining trend, and solar actually represents a category of "new renewables" that includes relatively small quantities of energy from wind and other renewable technologies.

Model description: MESSAGE is a linear optimization model that seeks to identify the least cost energy supply portfolio to meet a demand profile exogenously generated in a spreadsheet that takes into account estimates for economic growth, population, wealth disparity, urbanization rates, and other determinants. MESSAGE is a systems engineering model that draws on a large array of energy technology options.

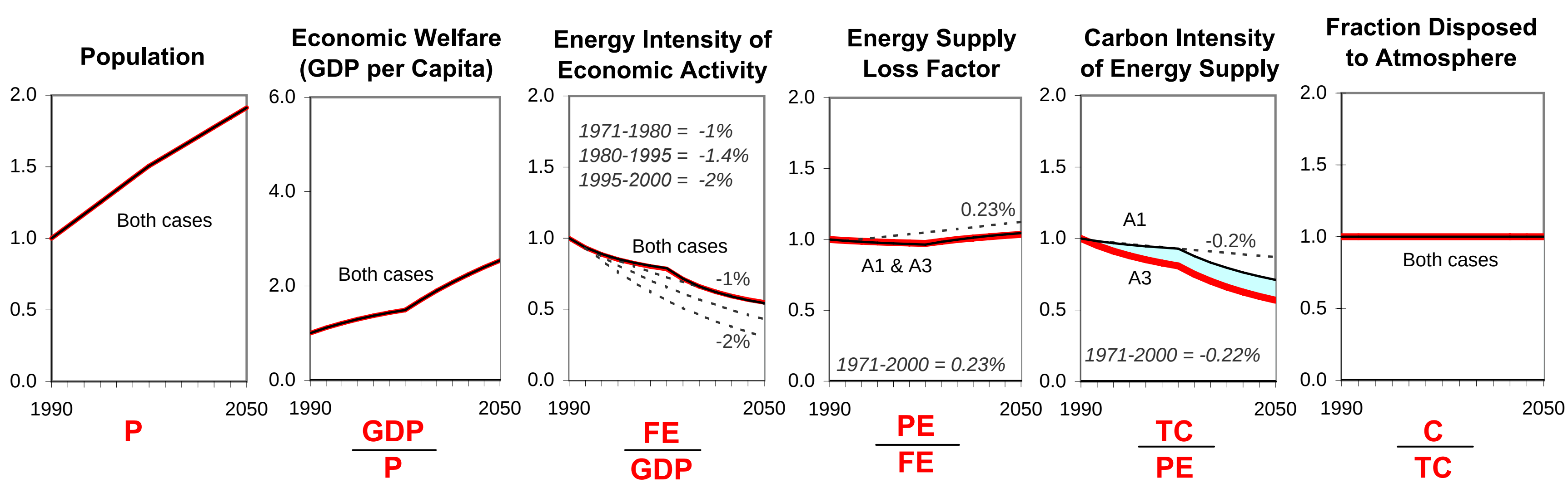
Key Observations on the Role of Renewables in this Scenario

Data is reported for 1990, 2020 and 2050, and linear interpolation is used to complete the plots. These two cases contrast technology development paths that treat traditional biomass and hydropower similarly in both cases. All "new renewables" - including modern biofuels - are reported as a single category. In the A3 case, the average annual rate of increase varies between 3-9%, driving the renewables share of primary energy above 30% by 2050. In comparison to the oil and gas case (A1), the nuclear and renewables case (A3) appears to have a much larger effect on natural gas than either nuclear power or renewables.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



II.14 Case B, Scenarios to 2050, World Energy Council & IIASA (1998)

Reference Case: How could the global energy system evolve in the context of modest estimates for economic growth and technological development?

Scenario narrative: Case B has the same population profile as the other cases (A & C), but it does not feature extremes of economic expansion or sustainability oriented initiatives. In this way, it is more "pragmatic," but it is also called "muddling through." Case B has slower rates of technological innovation, and thus, a carbon-intensive fuel mix. Depletion of fossil resources without counterbalancing technological progress forces more dramatic changes in energy supply structures. Fossil fuels remain available by moving into costlier categories of conventional and unconventional resources.

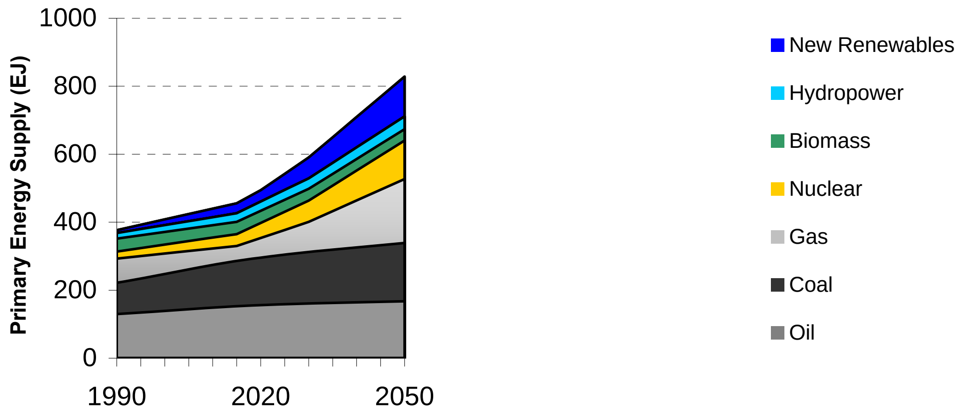
Model description: MESSAGE is a linear optimization model that seeks to identify the least cost energy supply portfolio to meet a demand profile exogenously generated in a spreadsheet that takes into account estimates for economic growth, population, wealth disparity, urbanization rates, and other determinants. MESSAGE is a systems engineering model that draws on a large array of energy technology options.

Key Observations on the Role of Renewables in this Scenario

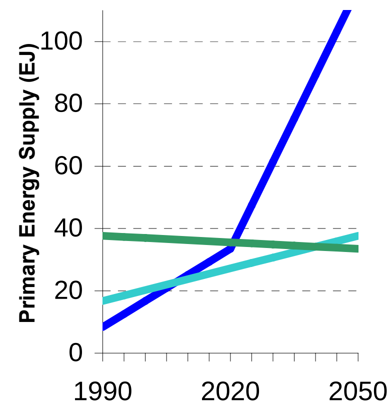
Data is reported for 1990, 2020 and 2050, and linear interpolation is used to complete the plots. Traditional biomass declines and hydropower increases along long-term prevailing trends. All "new renewables" - including modern biofuels - are reported as a single category. In the B case, the average annual rate of increase varies between 3-7%, driving the renewables share of primary energy above 20% by 2050.

Global Primary Energy Supply Profile

Case B: "Muddling Through"

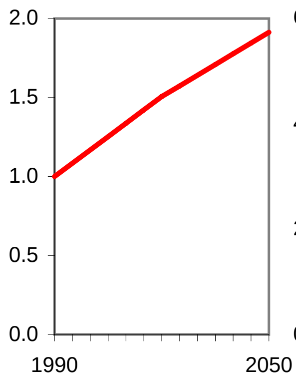


Renewables in Case B



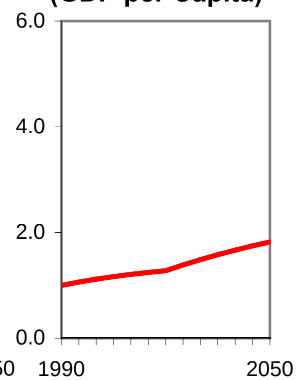
Key Driver Metrics, Indexed to 1990 = 1

Population



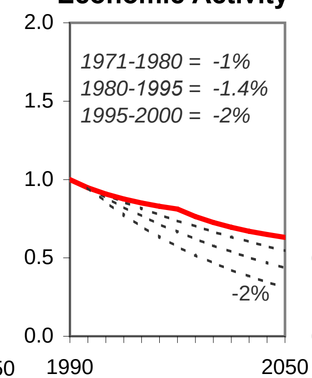
P

Economic Welfare (GDP per Capita)



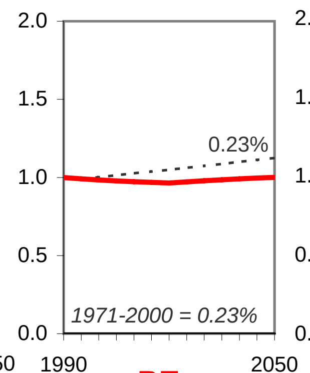
$\frac{GDP}{P}$

Energy Intensity of Economic Activity



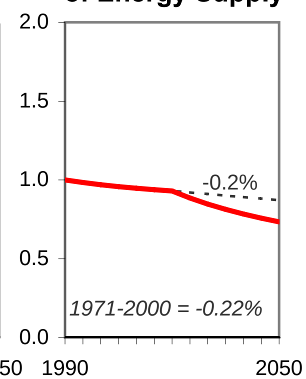
$\frac{FE}{GDP}$

Energy Supply Loss Factor



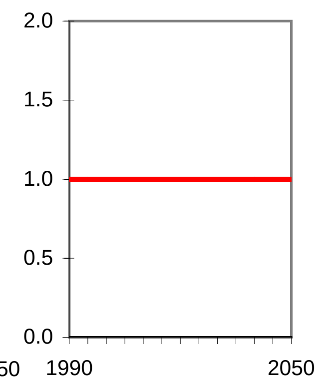
$\frac{PE}{FE}$

Carbon Intensity of Energy Supply



$\frac{TC}{PE}$

Fraction Disposed to Atmosphere



$\frac{C}{TC}$

II.15 Case C, Scenarios to 2050, World Energy Council & IIASA (1998)

Note: *This is not a Reference & Intervention pair of scenarios. Instead, it is a comparison of two scenarios with fundamentally different technology development paths in the context of similar demographic conditions.*

Reference Case: How might the global energy system evolve under the best possible circumstances of international cooperation and environmental conciousness - and with a phase out of nuclear power?

Alternative Case: How might the global energy system evolve under the best possible circumstances of international cooperation and environmental conciousness - and with a resurgence of nuclear power?

Scenario narrative: Case C is optimistic about technology and geopolitics, and it assumes unprecedented progressive international cooperation focused explicitly on environmental protection and international equity. A broad portfolio of environmental control technologies and policies, including incentives to encourage energy producres and consumers to utilize energy more efficiently and carefully, "green" taxes, international environmental and economic agreements, and technology transfer. Case C involves substantial resource transfers from industrialized to developing countries, spurring growth in the South. These resource transfers reflect strigent international environmental taxes or incentives, which recycle funds from the OECD to developing countries. Case C also incorporates policies to reduce carbon emissions in 2100 to 2 GtC per year, less than one third of the present emissions rate. Case C is split between C1, in which nuclear power is phased out by the end of the century, and C2, in which a new generation of nuclear reactors is developed, finds widespread social acceptability.

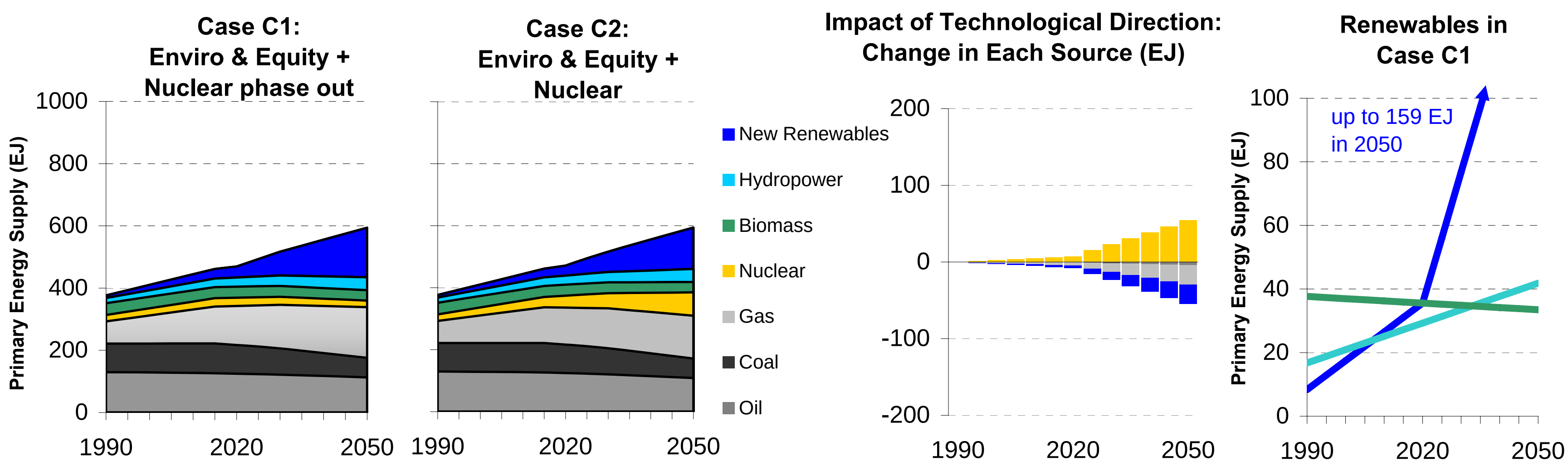
Model description: MESSAGE is a linear optimization model that seeks to identify the least cost energy supply portfolio to meet a demand profile exogenously generated in a spreadsheet that takes into account estimates for economic growth, population, wealth disparity, urbanization rates, and other determinants. MESSAGE is a systems engineering model that draws on a large array of energy technology options.

Key Observations on the Role of Renewables in this Scenario

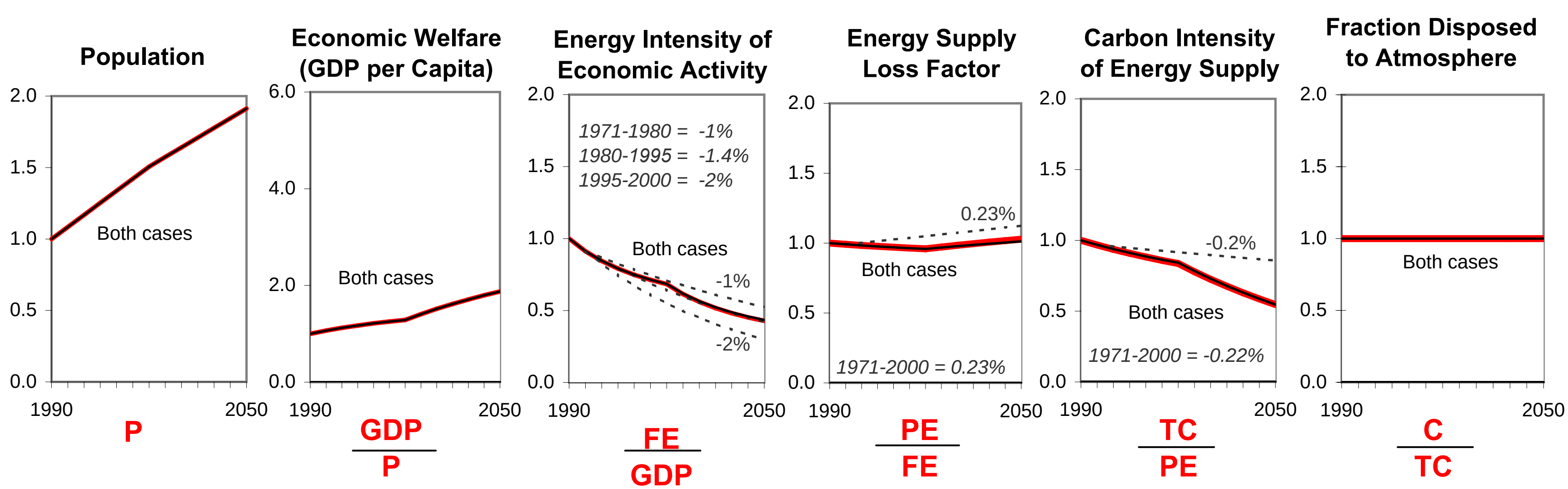
Data is reported for 1990, 2020 and 2050, and linear interpolation is used to complete the plots. As in scenarios A and B (II.12 and II.13), these two cases contrast technology development paths that treat traditional biomass and hydropower similarly in both cases, following long-term trends. All "new renewables" - including modern biofuels - are reported as a single category.

Lower overall demand is a striking difference in the C cases compared to A and B (Appendix II.12 and II.13). The C cases feature a rate of improvement in final energy intensity of economic activity that matches the prevailing global trend from 1980 to 2000, while the A and B cases are more pessimistic. As a result, the development of "new renewables" can proceed at pace similar to the B case, but claim approximately twice share of the global energy portfolio. (Approximately 40% of all energy is delivered by some form of renewables by 2050.) The C1 case indicates that in the absence of the additional nuclear power capacity in C2, the substitution of renewables is approximately 40%.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



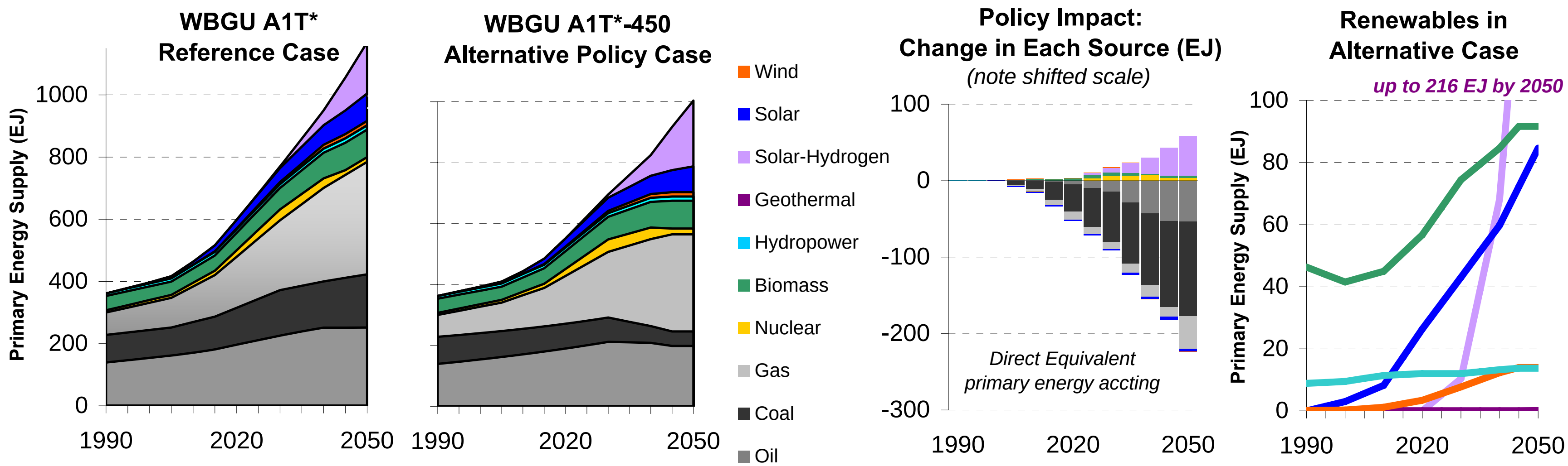
II.16 A1T*-450ppmv, WBGU & IIASA (2003)

Reference case	How could the global energy system evolve if a future with low population growth tended strongly toward high economic growth and rapid technological innovation?
Alternative case	How could the global energy system evolve if all nations participated in a climate stabilization framework and uses of certain zero carbon technology options (e.g. nuclear power, biomass) were also limited?
Scenario narrative	The A1 storyline describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with substantial reduction in regional differences in per capital income. A1T is a "dynamic technology" scenario variation of the A1 storyline that emphasizes very high technological improvement rates driven by market mechanisms and policies to promote innovation that favor non-fossil technologies and synfuels, especially hydrogen from non-fossil sources. In A1T, additional end-use efficiency improvements are assumed to take place with the diffusion of new end-use devices for decentralized production of electricity (fuel cells, microturbines). This study explores the potential to stabilize atmospheric carbon dioxide concentrations at 450 parts per million. The implicit policy intervention is a worldwide cap and trade program with full participation and low transaction costs. Although the constraint on carbon sequestration WBGU applied to the B1 scenario are not applied here, the study did impose other constraints on this future, including: a worldwide phase out of nuclear power by 2100 as well as limits to biomass use and hydropower to approximately double present levels.
Model description	MESSAGE is a linear optimization model that seeks to identify the least cost energy supply portfolio to meet a demand profile exogenously generated in a spreadsheet that takes into account estimates for economic growth, population, wealth disparity, urbanization rates, and other determinants. MESSAGE is a systems engineering model that draws on a large array of energy technology options.

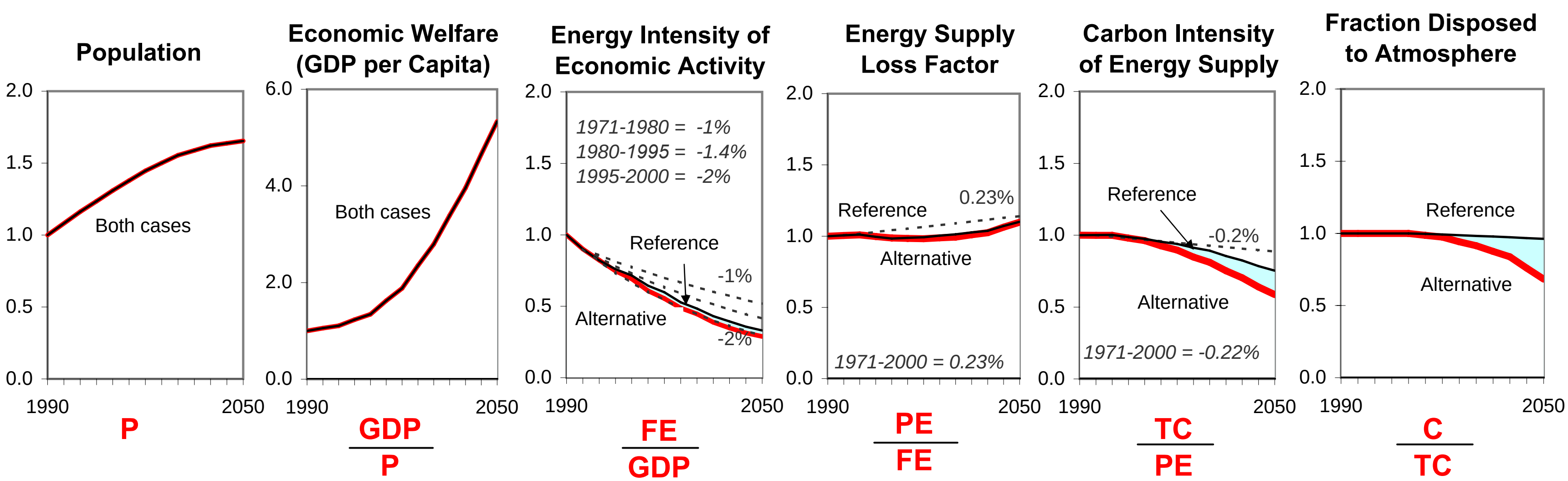
Key Observations on the Role of Renewables in this Scenario

Use of renewable energy technologies - and especially the dramatic entrance of solar-sourced hydrogen - in the exploratory reference case (A1T) is extensive even before a constraint on carbon emissions is imposed. The carbon constraint to 450ppm drives 25% of the fossil fuels (mostly coal) out of the global energy mix by 2050. These supplies are largely replaced with improvements to efficiency. Though the improvement to final energy intensity of economy appears small, the leverage on the system is large. The MESSAGE model characterization of solar-sourced hydrogen starting in 2020 appears to have a lower cost than wind power or solar power (photovoltaic, thermal electric, and solar heat), so virtually all of the new supply is solar-sourced hydrogen. Because solar-sourced hydrogen and nuclear power are treated with the direct equivalent method, their role in the energy mix as a replacement for thermal electric power is understated in these graphs. To meet the climate stabilization target, carbon sequestration in 2050 reaches a mass equivalent to 30% of all carbon generated in the energy sector.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1



II.17 B1*-400ppmv, WBGU & IIASA (2003)

Reference case

How could the global energy system evolve if a future with low population growth tended strongly toward efficiency and dematerialization?

Alternative case

How could the global energy system evolve if all nations participated in a climate stabilization framework and uses of certain zero carbon technology options (e.g. nuclear power and carbon sequestration) were also limited?

Scenario narrative

The B1 storyline describes a convergent world with low population growth and rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

This study explores the potential to stabilize atmospheric carbon dioxide concentrations at 400 parts per million. The implicit policy intervention is a worldwide cap and trade program with full participation and low transaction costs. WBGU placed additional constraints on this future, including: a worldwide phase out of nuclear power and carbon sequestration by 2100, limit to cumulative sequestration of 300 GtC, limits to biomass use and hydropower to approximately double present levels.

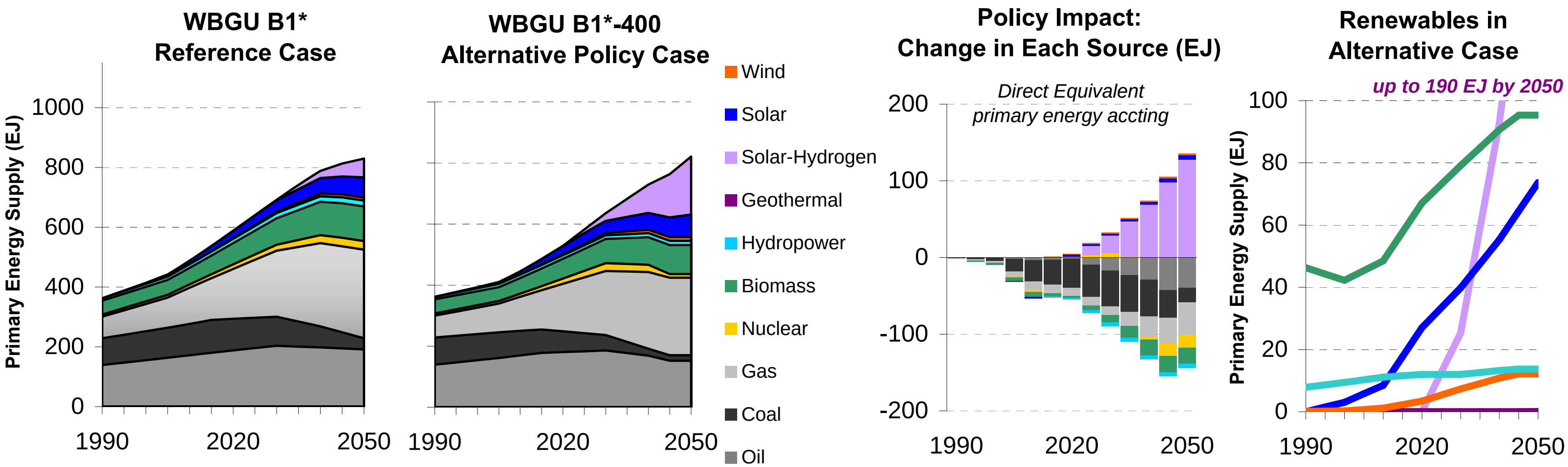
Model description

MESSAGE is a linear optimization model that seeks to identify the least cost energy supply portfolio to meet a demand profile exogenously generated in a spreadsheet that takes into account estimates for economic growth, population, wealth disparity, urbanization rates, and other determinants. MESSAGE is a systems engineering model that draws on a large array of energy technology options.

Key Observations on the Role of Renewables in this Scenario

Compared to all other reference cases reviewed in this report, use of renewable energy is most extensive in this exploratory reference case because the B1 storyline describes a relatively low-carbon future - or a type of best-case scenario for climate change in the absence of climate policy. The carbon constraint to 400ppm drives even more fossil fuels out of the global energy mix, and the limits placed by WBGU on other alternatives results in declining contributions from biomass, hydropower, and nuclear power. The MESSAGE model characterization of solar-sourced hydrogen starting in 2020 appears to have a lower cost than wind power or solar power (photovoltaic, thermal electric, and solar heat), so virtually all of the displaced supply is replaced with a modest quantity of efficiency in the early periods and a strikingly large quantity of solar-sourced hydrogen. Because solar-sourced hydrogen is treated with the direct equivalent method, its role in the energy mix as a replacement for thermal electric power is understated in these graphs. To meet the climate stabilization target, carbon sequestration in 2050 reaches a mass equivalent to 40% of all carbon generated in the energy sector.

Global Primary Energy Supply Profile



Key Driver Metrics, Indexed to 1990 = 1