# Hedging Strategies for Global Dioxide Abatement: A Summary of Poll Reults – EMF 14 Subgroup Analysis for Decisions under Uncertainty

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## A Summary of Poll Results

## EMF 14 Subgroup -- Analysis for Decisions under Uncertainty

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* This report summarizes a collective effort. William Nordhaus was the principal architect of the guidelines for scenarios. Other active participants included: Minh Ha Duong, James Hammitt, Charles Kolstad, Stephen Peck, Thomas Teisberg, and Gary Yohe. Helpful comments have been received from Richard Richels and John Weyant. The author is much indebted to Fehmi Ashaboglu and Joel Singer for research assistance. Financial support was provided by the Center for Economic Policy Research of Stanford University.

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## 1. Introduction - hedging strategies

The global warming problem resembles the dilemma faced by a driver on a foggy road. It is desirable to move rapidly toward one's destination, but one's speed must be governed by the distance that one can see ahead, and by the ability to make rapid changes in direction. Reasonable people will differ in their estimates of these factors. A driver does not automatically determine his speed on the basis of worst-case scenarios such as brake failure.

A prudent decision maker allows for the possible costs of rapid mid-course corrections, and hedges his bets against both upside and downside risks. Any of the current projections can be wrong. The extremely pessimistic outcomes are headline-grabbing, but they are not a sure thing. Their probabilities need to be considered in the design of global emissions strategies.

This report compares the application of these ideas within seven of the models participating in Energy Modeling Forum Study 14, Integrated Assessment of Climate Change. The acronyms of these models and the most recent documentation for each is shown in Table 1. They differ in terms of the degree to which they include details concerning regions, energy supply and conservation technologies, the carbon cycle and climate impacts. They all, however, share a common approach: the belief that policy-relevant results can be obtained by comparing the abatement strategies associated with a favorable versus an unfavorable (low probability, high consequence) scenario.

For a general overview of hedging strategies, see Figure 1. This contrasts two alternative ways to think about the greenhouse issue when there are just two possible outcomes: a favorable and an unfavorable one. One is an upside possibility, the other is a downside risk. The topmost panel describes a scenario as though all uncertainties were resolved prior to decision-making. In a "scenario" approach such as this one, we have the opportunity to learn whether the state of the world is favorable or unfavorable *before* taking action. The panel shows the decision tree for this "learn-then-act" (LTA) viewpoint. A circle denotes a chance node - a point at which the uncertainties are resolved. A square denotes a decision node - a point at which actions are required.

The bottom panel shows an alternative way to look at things. This viewpoint is characterized by the phrase "act-then-learn" (ATL). For illustrative purposes, it is assumed that global CO2 uncertainties are resolved sometime shortly after 2020. Prior to 2020, the energy sector's supply and conservation investment decisions must be made under uncertainty about the importance of limiting carbon emissions. Thereafter, the uncertainties are resolved. The ATL approach is a pragmatic one. It is *not* designed for producing accurate long-range forecasts. Rather, it emphasizes the importance of near-term decisions, how they are affected by long-term uncertainties, and how much one should be willing to pay for the timely resolution of those uncertainties.

## 2. Guidelines for scenarios

By focusing on hedging strategies for low probability, high consequence scenarios, this model comparison study has adopted a deliberately parsimonious design. We contrast just two out of many possibilities. One is described as a base (or reference) case; the other is a low probability, highly unfavorable case. At some point, it would be instructive to do a systematic analysis of more than two scenarios.

In designing the two alternatives, we took advantage of preliminary work that had been undertaken by several of the participants in the EMF 14 study. These enabled us to screen out several plausible sources of uncertainty and to focus on those that were likely to have a major impact on near-term decisions. For example, differences in GDP growth rates during the mid- to late 21st century could have major impacts on carbon emissions during that period, but not prior to 2020.

The meaning of the underlying probabilities must be carefully defined. They refer to "judgmental" and "subjective" distributions, and are not derived from empirical observations of relative frequencies. For a readable overview of these issues, see Raiffa (1968).

For reasons of practicality, we had to define uncertainties in a way that could be incorporated in as many of the participating models as possible, and to reduce the computational burden upon them. The uncertainties had to be chosen in a way that would allow unambiguous interpretation, would be easily understandable by policy makers, and would have significant impacts upon near-term decisions. In addition, it was desirable to employ variables that had been the subject of surveys of expert opinion. In this way, we hoped to reduce the arbitrariness of the probability judgments that are central to this type of decision analysis.

After reviewing the earlier work, it appeared that there were only two parameters that appeared to meet all of these criteria: the mean temperature sensitivity factor and the cost of the damages associated with global warming. More precisely, *climate sensitivity* is the equilibrium temperature change that would occur if atmospheric CO2 concentrations were to double from their preindustrial level of around 275 ppmv (parts per million, by volume). *Warming damages* are defined as the economic losses that would occur if CO2 doubling in the late 21st century were to produce, say, a 3 degree C. warming from the preindustrial level. These losses include both market damages and the willingness-to-pay for avoiding non-market damages. Inherently, there is a good deal of uncertainty if we are to allow for all the potential surprises and adaptive measures that might be taken in response to this rate of global warming.

The next question to be decided was the numerical values of the two parameters being investigated. The group discussed alternative values and eventually concluded that it would be useful to define the unfavorable cases as the top 5 percent of each of these

After completing the study reported here, we realized that a third uncertain parameter had a major impact on near-term decisions: the rate at which future costs and benefits are to be discounted. Because of its controversial nature, the overall EMF 14 study had not attempted to standardize its value. The only guidance is to be found in a single sentence that appears in the guidelines: "If your model does not calculate a discount rate internally, assume that the near-term marginal product of capital is 5 percent." In our model comparisons, we will see that the discount rate can make a major difference in near-term decisions and in the value of information.

## 3. Four LTA scenarios - average model results

In order to perform a controlled comparison between the base case and the three unfavorable scenarios, we begin with the LTA (learn, then act) approach. Figure 2 is a conventional sensitivity analysis. It shows how an economically efficient carbon emissions trajectory might be affected by the climate and damage parameters, and it reports the average carbon emissions projected by the seven participating models.

Under U0 (the base case), emissions rise steadily throughout the 21st century. According to the other cases, climate sensitivity has a smaller impact than the warming damage parameter. Even under U2 (high climate sensitivity), emissions rise during the next 50 years. It is only when we incorporate a high value for the warming damage parameter (cases U1 and U3) that it becomes desirable to stabilize or reduce global emissions during the next few decades. As might be expected, the greatest difference in emissions occurs when we compare the base scenario U0 with the low probability, high consequence unfavorable scenario U1. For this reason, we will concentrate on these two alternatives when we turn to the ATL (act, then learn) view of the world.

Figures 3-5 show the average model projections of concentrations, temperature change and the value of emission rights. Except for carbon emissions, not all of these values were reported by all seven models. For details on the coverage and for the actual values reported by each model, see the attached spreadsheet tables.

Carbon inflows are a small fraction of atmospheric stocks, and there is a long time lag before concentrations are translated into equilibrium temperature changes. This is why changes in emissions (Figure 2) make their way only slowly into changes in concentrations (Figure 3) and even more slowly into temperature changes (Figure 4).

The value of carbon emission rights (alternately termed "carbon taxes") are indicators that could be useful for the decentralized implementation of globally efficient abatement scenarios. These values suggest how the payoffs might vary from different research and development strategies. According to Figure 5, they represent the most volatile series reported by the participants in this study. Each model has a somewhat different approach for determining the optimal mix between the costs and the benefits of the decades through 2020, *none* of the models indicate that it is economically efficient to aim for global emissions stabilization. The increases are modest in the case of DIAM, but substantial in the case of DICE. These two models are distinguished by dashed lines.

Beyond 2020, there is no simple way to characterize the differences between models. Under the favorable U0 scenario (Figure 7), all but one of them (MERGE) indicate that emissions will continue to rise after 2020.

Figure 8 shows how the models react to the unfavorable U1 scenario. The only valid generalization is that in 2020 (upon the resolution of uncertainties), there is an abrupt change in the trend of carbon emissions. DICE, SLICE and YOHE report that it is optimal to stabilize emissions from the middle of the century onward, but the other four models show a decline to virtually zero by the end of the century. Opinions will differ on whether these are reasonable estimates of decarbonization rates. The answer will depend upon what one assumes with respect to the system's inertia and the costs of abrupt changes in direction. In terms of the foggy road analogy, these models provide alternative estimates of how rapidly a driver might attempt to apply the brakes under unfavorable circumstances.

Figures 9 and 10 report the value of carbon emission rights under the two scenarios. For the year 2000, most of the models indicate a modest but positive carbon tax ($5 - $10 per ton). There is a general tendency for these values to increase over time. By definition, the value of carbon emission rights is identical for scenarios U0 and U1 between 2000 and 2020. Immediately thereafter, there is a bifurcation - a decline in the favorable scenario U0 and a sharp jump in the unfavorable scenario U1. (See Figure 10.) Carbon values then exceed $100 per ton, and in some cases exceed $1000. CETA is the only model in which carbon values are limited by a backstop assumption ($465 per ton).

## 5. The value of information

Individual observers will assign very different subjective probabilities to scenarios such as U0 and U1. For this reason, it is useful to compare results at a single point in time, but with differing values of these probabilities. For concreteness, Figure 11 compares the ATL and LTA projections of carbon emissions in 2020 - just before the date at which the climate and impact uncertainties are resolved.

The horizontal axis indicates the relative likelihood of U0 and U1. Let p(U0) denote the probability of the base scenario. When this is close to 100%, the ATL results virtually coincide with those for U0-LTA. Conversely, when p(U0) is close to zero, the ATL results coincide with those for U1-LTA. If one took a very different position than the guidelines

In an ATL world, we cannot avoid making one or the other type of error. This is why the ATL curve (solid line) lies uniformly below the LTA dashed line. The vertical difference is termed the "expected value of perfect information" - for short the EVPI. E.g., with p(U0) = 50%, the vertical distance is about $5 trillions. This is the amount that informed decision makers would be willing to pay for an immediate determination of whether they were in a U0 or a U1 world. A perfect forecast would enable them to avoid both types of errors during the decades prior to 2020. The EVPI has an analogy within the game of bridge. There this principle is known as "one peek is worth two finesses". That is, additional information can often help, and it never hurts.

According to Figure 12, the EVPI is virtually zero when p(U0) is either very low or very high. It is at its maximum when the uncertainty is greatest - a 50% probability of each scenario. Accordingly, it should come as no surprise that all of our models report the EVPI at under $100 billion dollars when employing the study group's guideline probabilities. That is, p(U1) = 0.25%. (See Table 2.) Even when undertaking a sensitivity analysis and assuming that p(U1) = 5%, all of the models reported an EVPI of less than a trillion dollars. In the case of MERGE, the EVPI was too small to be detected by the optimization algorithm, and accordingly this value was reported as zero.

Several additional observations on the EVPI results reported in Tables 2 and 3:

(1) The lower the discount rate, the higher become the expected benefits of taking immediate steps to reduce emissions. This is why the one model that employs a 3% discount rate (DIAM) tends to show a higher EVPI than those models that employ discount rates of 5%. When MERGE is modified to allow for a 3% discount rate, the EVPI becomes comparable with that of DIAM.

2) CETA, DIAM, HCRA and SLICE reported EVPI results for a 2050 as well as a 2020 date of resolution of the uncertainties. The later the date of resolution, the greater become the cumulative errors of either too much or too little abatement. This is why the EVPI grows with the length of time prior to the resolution of uncertainty.

(3) When comparing U0 with the U2 scenario, there is not a great potential for costly errors in the choice of abatement strategies. (Recall the similarity between the U0 and U2 carbon emission paths prior to 2020 in Figure 2.) This is why both CETA and SLICE show low EVPI values for this pair of scenarios in Table 3. There is a somewhat higher potential for costly errors when comparing the U0 and U3 emission paths. Accordingly, CETA and SLICE both show higher EVPI values for the U0-U3 scenario comparison. (Again see Table 3.)

(4) In a separate report, Chang (1995) has shown that when MERGE is modified to allow simultaneously for all four possibilities (U0, U1, U2 and U3) instead of just two contrasting scenarios, there can be a considerable increase in the EVPI.

Table 3. Additional EVPI results (unit: billion dollars)

| Resolution date | 2020 | 2050 |
|---|---|---|
| SLICE (5% discount rate): | | |
| U0 (95%) vs. U2 (5%) | 1 | 2 |
| U0 (95%) vs. U3 (5%) | 38 | 101 |
| CETA (4% discount rate): | | |
| U0 (95%) vs. U2 (5%) | 12 | 27 |
| U0 (95%) vs. U3 (5%) | 136 | 267 |

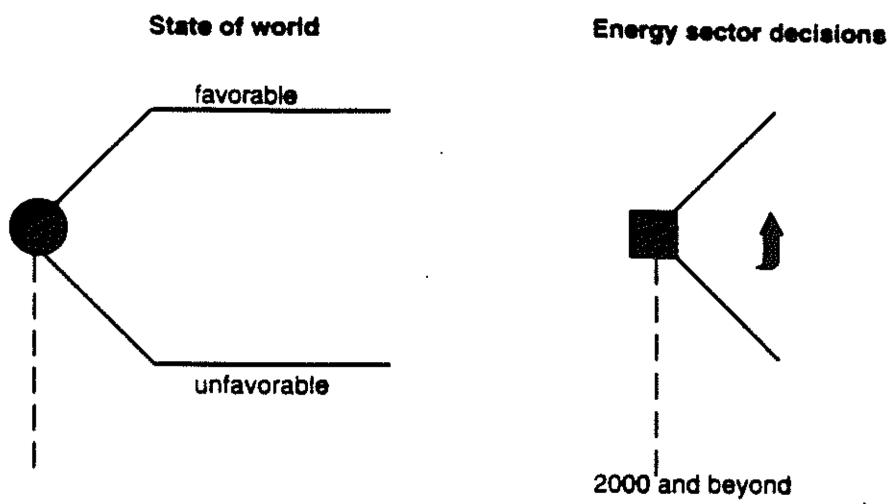
## 6. Concluding comments

This paper has emphasized the concept of hedging strategies for dealing with uncertainty. It is misleading to interpret such strategies as an argument for a do-nothing policy. Delay should not be confused with inaction. There is widespread agreement that we need to maintain a broad portfolio of options for dealing with global climate change. According to most of the participating models, it would be desirable to institute a modest carbon tax in the near future ($5 - $10 per ton in the year 2000), and to have that tax increase over time.

During the next few decades, we will learn how far we can get with "no regrets" energy conservation policies. It is important to continue intensive science research to reduce climate and impact uncertainties. Our energy research and development efforts must be directed toward cost-effective conservation and to low-carbon supply technologies. Immediate reduction of emissions is only one among several competing possibilities. The issue is not one of either-or, but of finding the right mix of policies.

Figure 1.

**Alternative Characterizations of Decision Problem**
**Learn-Then-Act (LTA)**




**Alternative Characterizations of Decision Problem**
**Act-Then-Learn (ATL)**

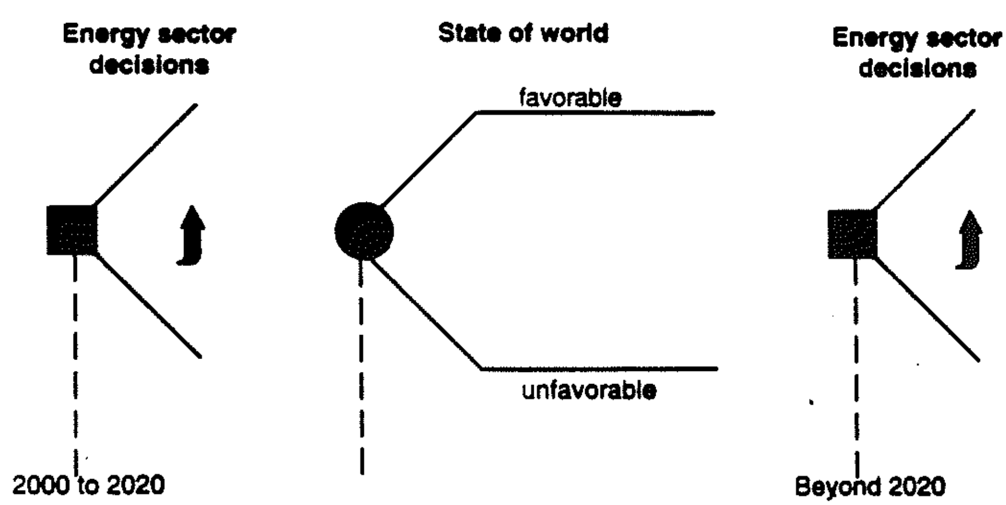


**Figure 3. Carbon Concentrations (average of all models, LTA)**

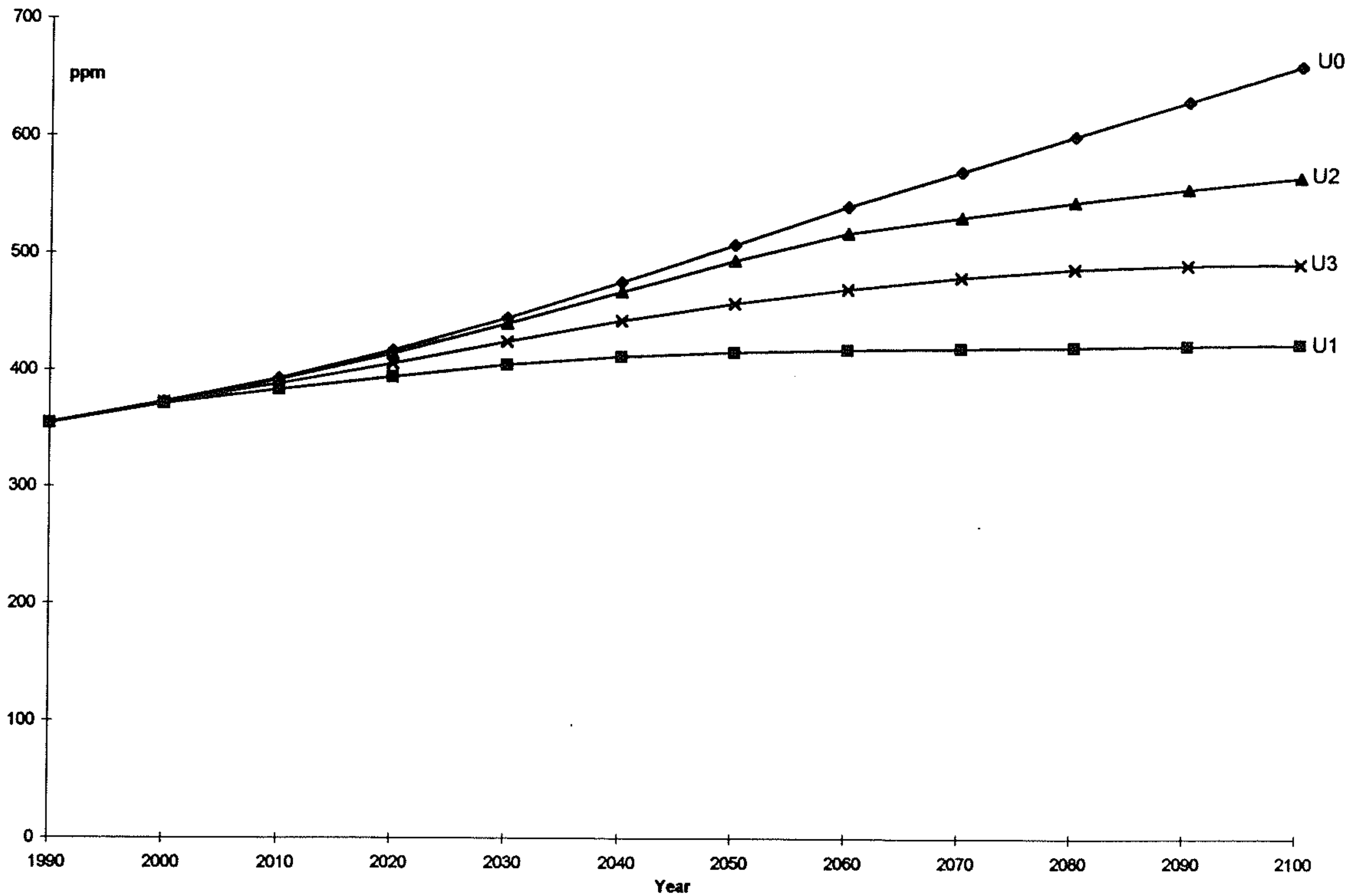


Figure 5. Value of Carbon Emission Rights
(average of all models, LTA)

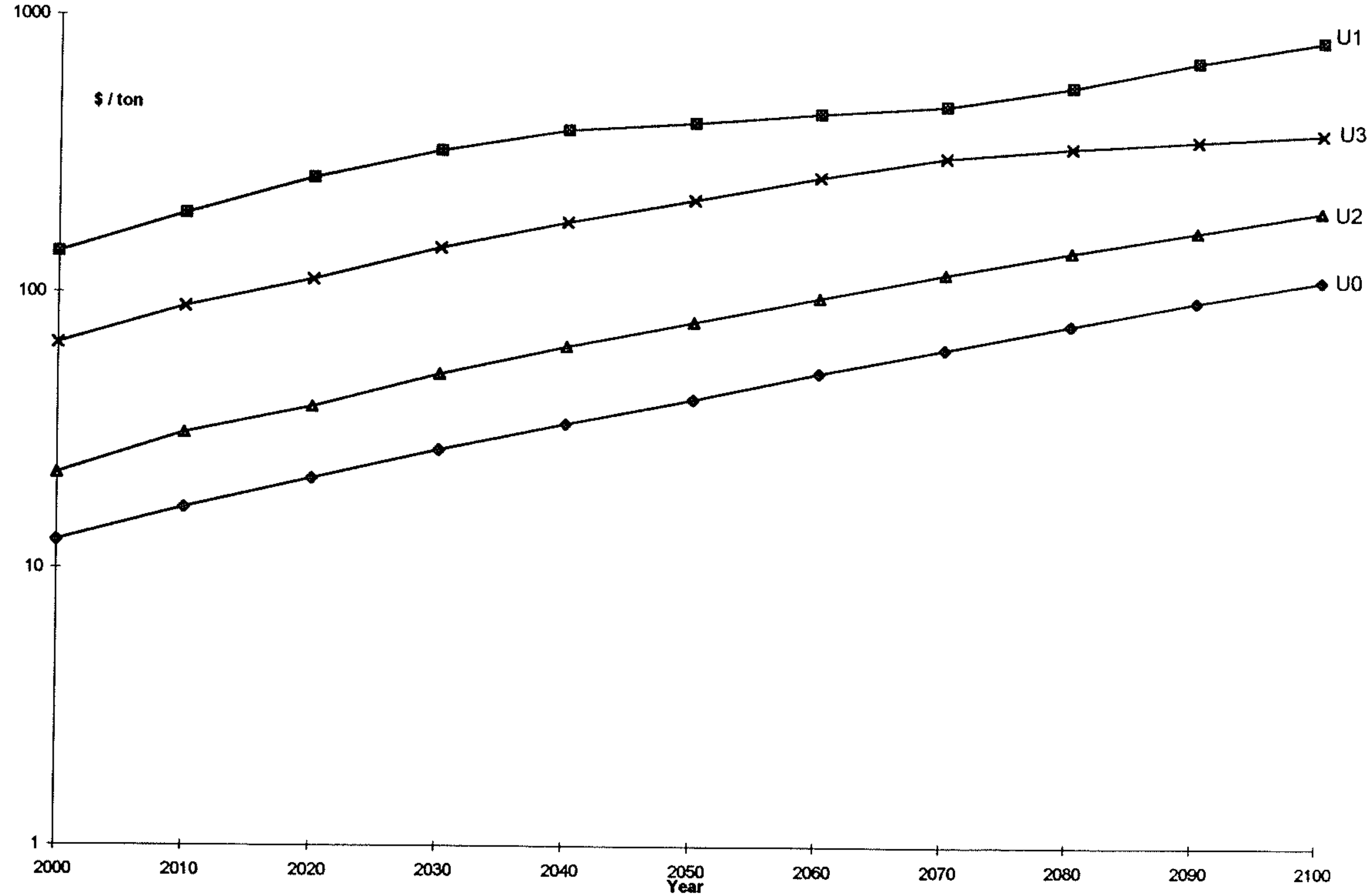


**Figure 7. Carbon Emissions (all models, U0-ATL)**

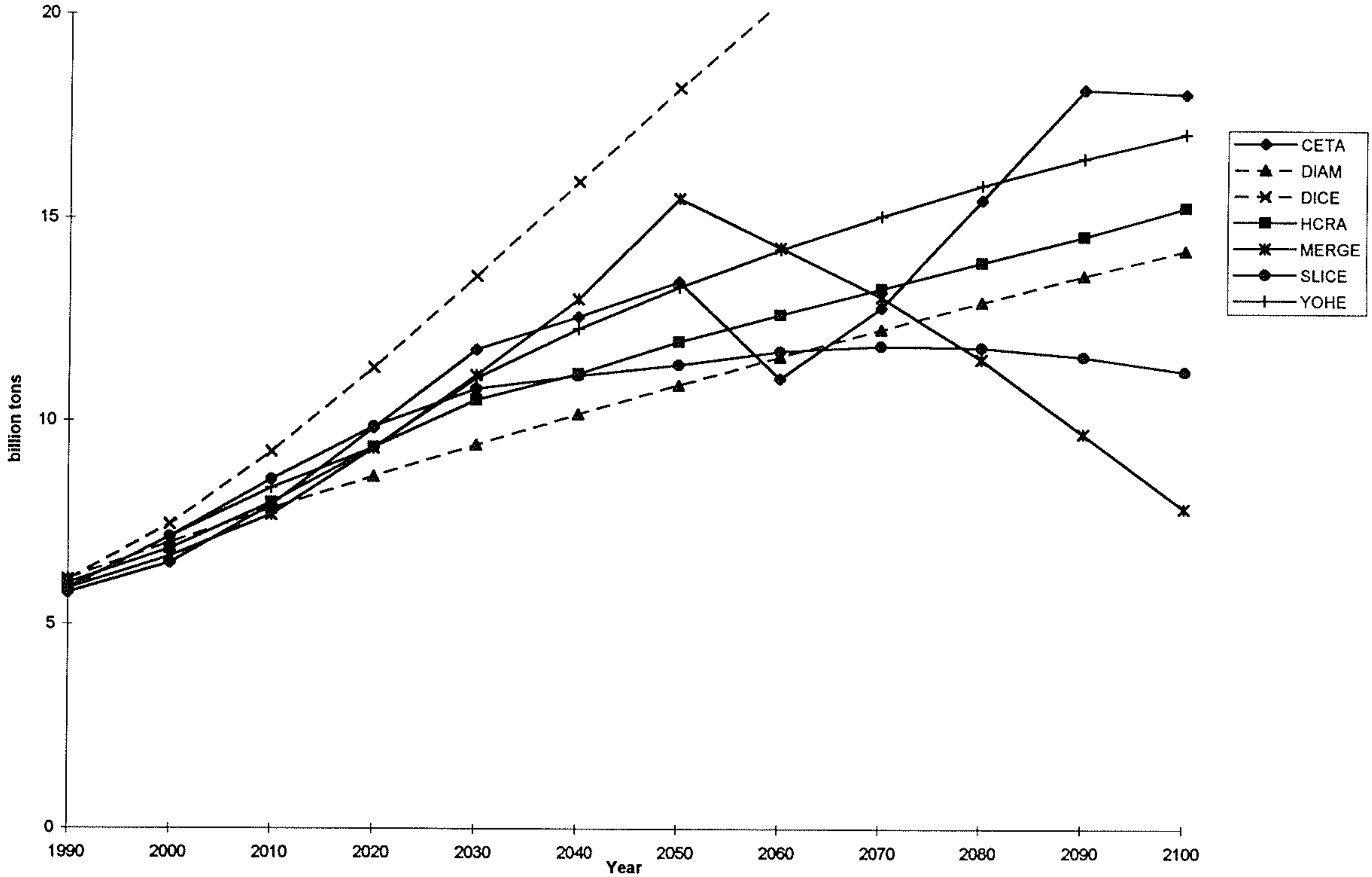
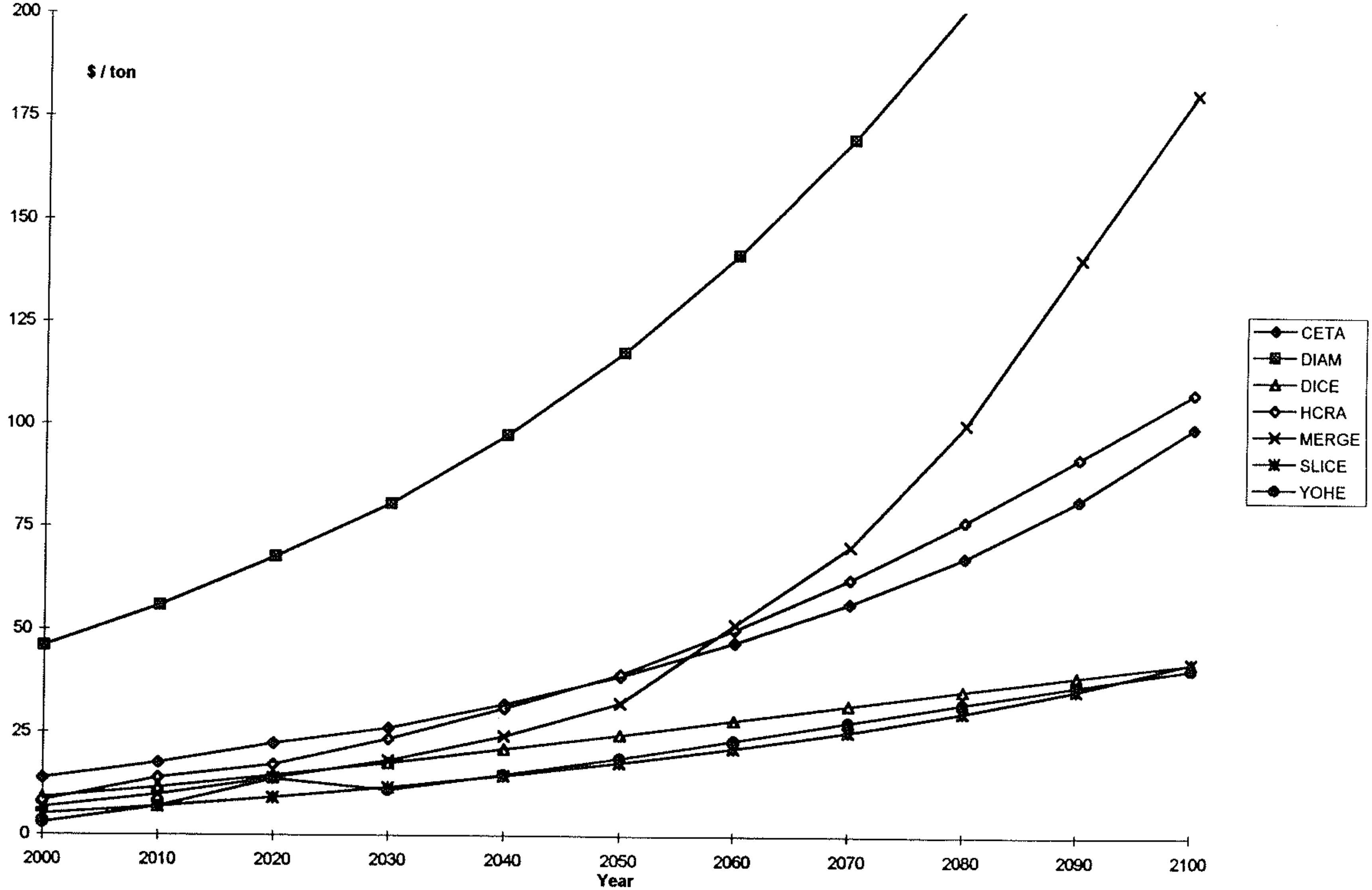
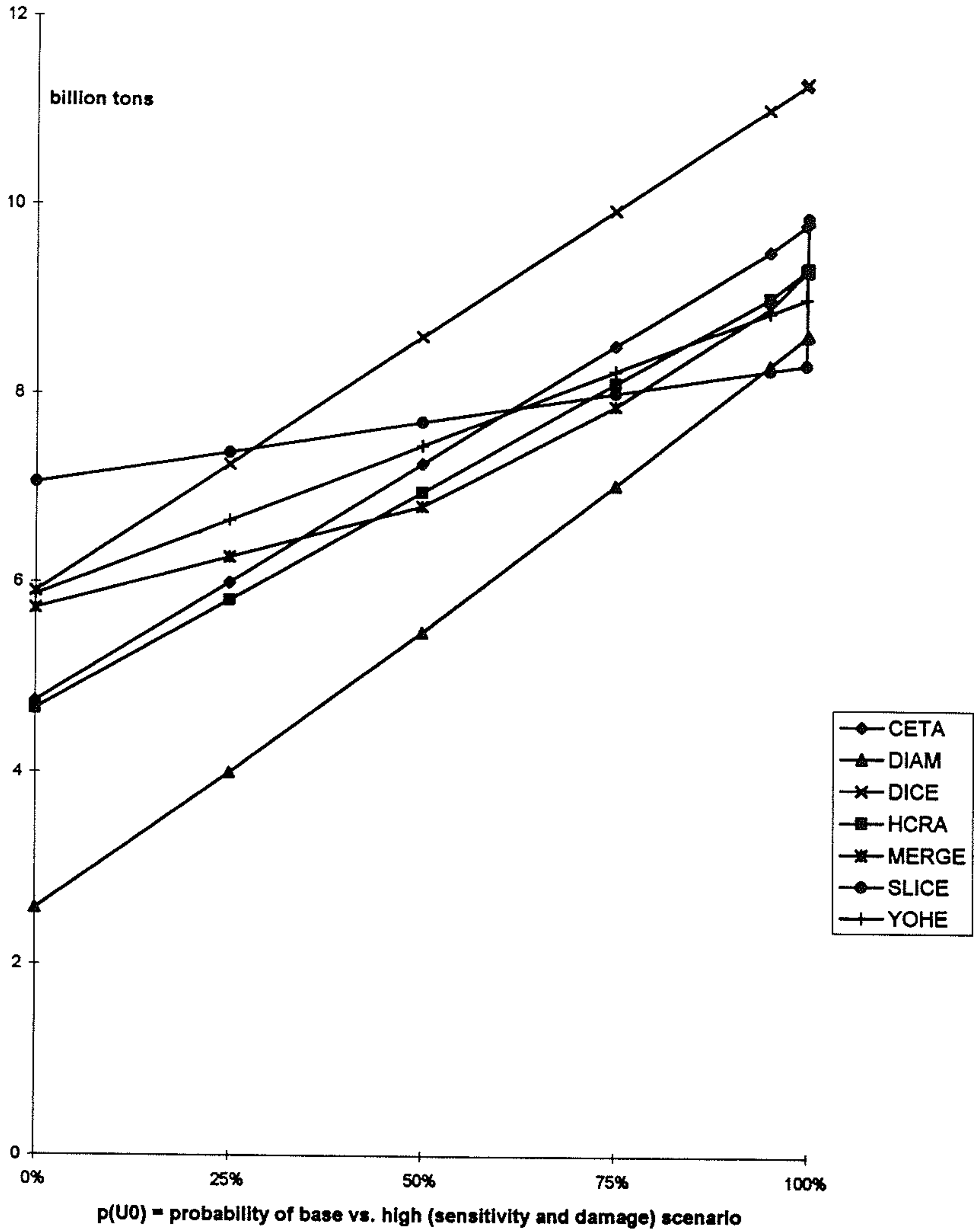


**Figure 9. Value of Carbon Emission Rights (all models, U0-ATL)**



# Figure 11. Carbon Emissions in 2020



| | EMF-14: Analysis for Decisions Under Uncertainty -- Data tables | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Organized by model, variable, then LTA U0..U3, ATL U0,U1 | | | | | | | | | | | |
| CETA: | | | | | | | | | | | | |
| | CO2 Emissions | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 5.760 | 6.510 | 7.930 | 9.850 | 11.770 | 12.570 | 13.450 | 11.060 | 12.810 | 15.470 | 18.200 | 18.150 |
| LTA U1 | 5.760 | 3.840 | 4.420 | 4.740 | 3.570 | 2.470 | 2.020 | 1.650 | 1.350 | 1.100 | 0.900 | 0.740 |
| LTA U2 | 5.760 | 6.250 | 7.540 | 9.260 | 10.880 | 11.240 | 10.440 | 4.550 | 3.900 | 3.380 | 2.940 | 2.590 |
| LTA U3 | 5.760 | 5.520 | 6.220 | 7.030 | 6.980 | 6.170 | 5.230 | 4.460 | 3.830 | 2.300 | 1.880 | 1.530 |
| ATL U0 | 5.760 | 6.500 | 7.920 | 9.830 | 11.770 | 12.570 | 13.440 | 11.060 | 12.810 | 15.460 | 18.190 | 18.090 |
| ATL U1 | 5.760 | 6.500 | 7.920 | 9.830 | 6.050 | 6.190 | 5.300 | 3.350 | 2.560 | 2.090 | 1.710 | 1.390 |
| ATL U2 | 5.760 | 6.490 | 7.910 | 9.820 | 10.860 | 11.310 | 10.860 | 6.010 | 5.100 | 4.350 | 3.740 | 3.240 |
| ATL U3 | 5.760 | 6.450 | 7.840 | 9.690 | 7.940 | 7.390 | 5.250 | 4.130 | 3.560 | 2.080 | 1.700 | 1.380 |
| ATL U0-50 | 5.760 | 6.490 | 7.910 | 9.820 | 11.710 | 12.470 | 13.180 | 11.030 | 12.800 | 15.460 | 18.180 | 18.010 |
| ATL U1-50 | 5.760 | 6.490 | 7.910 | 9.820 | 11.710 | 12.470 | 13.180 | 4.760 | 3.890 | 3.180 | 2.600 | 2.120 |
| ATL U2-50 | 5.760 | 6.490 | 7.910 | 9.820 | 11.710 | 12.480 | 13.230 | 8.050 | 6.760 | 5.710 | 4.850 | 4.150 |
| ATL U3-50 | 5.760 | 6.450 | 7.850 | 9.720 | 11.570 | 12.260 | 12.780 | 5.700 | 4.840 | 4.140 | 2.550 | 2.090 |
| | | | | | | | | | | | | |
| | Carbon Concentrations | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 359.390 | 378.500 | 397.620 | 421.930 | 452.240 | 487.930 | 523.350 | 559.640 | 581.590 | 612.050 | 652.460 | 701.510 |
| LTA U1 | 359.390 | 378.500 | 385.120 | 395.670 | 406.700 | 411.470 | 411.780 | 411.180 | 409.800 | 407.870 | 405.600 | 403.140 |
| LTA U2 | 359.390 | 378.500 | 396.420 | 419.150 | 447.200 | 479.570 | 510.090 | 534.320 | 529.870 | 527.290 | 524.420 | 521.310 |
| LTA U3 | 359.390 | 378.500 | 393.000 | 410.290 | 429.490 | 446.640 | 458.880 | 466.650 | 471.380 | 473.980 | 470.300 | 466.620 |
| | | | | | | | | | | | | |
| | Temperature Change | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 0.000 | 0.170 | 0.410 | 0.630 | 0.850 | 1.080 | 1.330 | 1.600 | 1.870 | 2.130 | 2.380 | 2.640 |
| LTA U1 | 0.000 | 0.320 | 0.710 | 1.040 | 1.350 | 1.630 | 1.880 | 2.090 | 2.260 | 2.400 | 2.510 | 2.600 |
| LTA U2 | 0.000 | 0.320 | 0.710 | 1.080 | 1.460 | 1.860 | 2.280 | 2.720 | 3.140 | 3.480 | 3.750 | 3.970 |
| LTA U3 | 0.000 | 0.170 | 0.410 | 0.620 | 0.820 | 1.020 | 1.210 | 1.390 | 1.560 | 1.710 | 1.830 | 1.940 |

| | Value of Carbon Emission Rights | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 10.100 | 12.980 | 16.560 | 20.940 | 26.150 | 32.000 | 38.870 | 47.200 | 56.690 | 67.940 | 82.000 | 100.030 |
| LTA U1 | 219.360 | 281.790 | 358.050 | 447.340 | 465.000 | 465.000 | 465.000 | 465.000 | 465.000 | 465.000 | 465.000 | 465.000 |
| LTA U2 | 27.270 | 35.520 | 45.800 | 58.470 | 73.610 | 90.930 | 111.320 | 136.290 | 165.810 | 201.170 | 245.140 | 299.930 |
| LTA U3 | 80.530 | 103.410 | 131.860 | 166.890 | 208.690 | 257.260 | 311.330 | 378.460 | 456.330 | 465.000 | 465.000 | 465.000 |
| ATL U0 | 10.710 | 13.790 | 17.610 | 22.290 | 26.150 | 32.000 | 38.860 | 47.200 | 56.700 | 67.950 | 82.020 | 100.050 |
| ATL U1 | 10.710 | 13.790 | 17.610 | 22.290 | 465.000 | 465.000 | 465.000 | 465.000 | 465.000 | 465.000 | 465.000 | 465.000 |

**DIAM:**

| | CO2 Emissions | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 6.097 | 6.994 | 7.844 | 8.655 | 9.433 | 10.181 | 10.903 | 11.602 | 12.281 | 12.946 | 13.600 | 14.244 |
| LTA U1 | 6.097 | 5.297 | 4.084 | 2.589 | 1.119 | 0.100 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| ATL U0 | 6.097 | 6.990 | 7.834 | 8.639 | 9.420 | 10.171 | 10.895 | 11.596 | 12.277 | 12.942 | 13.597 | 14.242 |
| ATL U1 | 6.097 | 6.990 | 7.834 | 8.639 | 5.517 | 2.810 | 0.815 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| | Carbon Concentrations | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 354.000 | 372.933 | 393.665 | 415.889 | 439.349 | 463.825 | 489.128 | 515.099 | 541.604 | 568.535 | 595.809 | 623.361 |
| LTA U1 | 354.000 | 369.707 | 380.329 | 384.952 | 383.571 | 377.573 | 369.930 | 362.711 | 356.071 | 349.964 | 344.348 | 339.182 |

| | Value of Carbon Emission Rights | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 0.000 | 45.431 | 55.105 | 66.772 | 80.809 | 97.649 | 117.782 | 141.748 | 170.118 | 203.469 | 242.323 | 287.054 |
| LTA U1 | 0.000 | 238.930 | 337.851 | 479.925 | 630.309 | 761.663 | 562.432 | 594.768 | 668.966 | 756.943 | 860.926 | 983.602 |
| ATL U0 | 0.000 | 45.915 | 55.812 | 67.805 | 80.809 | 97.649 | 117.782 | 141.748 | 170.118 | 203.469 | 242.323 | 287.054 |
| ATL U1 | 0.000 | 45.915 | 55.812 | 67.805 | 630.309 | 761.664 | 918.703 | 842.200 | 668.966 | 756.943 | 860.936 | 983.602 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DICE:** | | | | | | | | | | | | |
| | CO2 Emissions | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 6.088 | 7.458 | 9.256 | 11.335 | 13.583 | 15.904 | 18.205 | 20.391 | 22.366 | 24.035 | 25.318 | 28.158 |
| LTA U1 | 6.088 | 4.750 | 5.336 | 5.904 | 6.410 | 8.840 | 7.197 | 7.490 | 7.732 | 7.934 | 8.113 | 8.280 |
| ATL U0 | 6.088 | 7.448 | 9.239 | 11.311 | 13.583 | 15.904 | 18.205 | 20.392 | 22.369 | 24.032 | 25.308 | 26.162 |
| ATL U1 | 6.088 | 7.448 | 9.239 | 11.311 | 6.523 | 6.887 | 7.305 | 7.595 | 7.768 | 7.863 | 8.154 | 8.316 |
| | | | | | | | | | | | | |
| | Carbon Concentrations | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0(N) | 736.400 | 775.709 | 820.510 | 873.082 | 934.584 | 1005.354 | 1085.082 | 1172.893 | 1267.380 | 1366.633 | 1468.302 | 1569.713 |
| LTA U1(N) | 736.400 | 775.709 | 803.179 | 832.114 | 862.273 | 893.156 | 924.221 | 954.983 | 985.057 | 1014.170 | 1042.156 | 1068.952 |
| LTA U0 | 353.000 | 371.843 | 393.319 | 418.520 | 448.001 | 481.926 | 520.144 | 562.237 | 607.530 | 655.108 | 703.844 | 752.456 |
| LTA U1 | 353.000 | 371.843 | 385.011 | 398.881 | 413.338 | 428.142 | 443.034 | 457.780 | 472.196 | 486.152 | 499.567 | 512.412 |
| | | | | | | | | | | | | |
| | Temperature Change | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0(N) | 0.430 | 0.522 | 0.665 | 0.844 | 1.051 | 1.283 | 1.537 | 1.809 | 2.092 | 2.384 | 2.677 | 2.967 |
| LTA U1(N) | 0.430 | 0.583 | 0.783 | 0.994 | 1.214 | 1.442 | 1.675 | 1.911 | 2.148 | 2.383 | 2.615 | 2.842 |
| LTA U0 | 0.000 | 0.092 | 0.235 | 0.414 | 0.621 | 0.853 | 1.107 | 1.379 | 1.662 | 1.954 | 2.247 | 2.537 |
| LTA U1 | 0.000 | 0.153 | 0.353 | 0.564 | 0.784 | 1.012 | 1.245 | 1.481 | 1.718 | 1.953 | 2.185 | 2.412 |
| | | | | | | | | | | | | |
| | Value of Carbon Emission Rights | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 0.000 | 8.810 | 11.300 | 14.250 | 17.540 | 21.020 | 24.630 | 28.280 | 31.920 | 35.510 | 39.010 | 42.430 |
| LTA U1 | 0.000 | 93.380 | 118.530 | 148.540 | 182.210 | 218.560 | 256.770 | 296.190 | 332.800 | 375.550 | 414.140 | 451.070 |
| ATL U0 | 0.000 | 9.020 | 11.570 | 14.580 | 17.540 | 21.020 | 24.630 | 28.280 | 31.920 | 35.510 | 39.010 | 42.430 |
| ATL U1 | 0.000 | 9.020 | 11.570 | 14.580 | 179.330 | 212.800 | 248.640 | 285.950 | 323.900 | 361.860 | 399.420 | 435.520 |

| HCRA: | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | CO2 Emissions | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 6.000 | 6.850 | 8.000 | 9.370 | 10.520 | 11.170 | 11.970 | 12.630 | 13.280 | 13.920 | 14.570 | 15.290 |
| LTA U1 | 6.000 | 5.010 | 4.490 | 4.660 | 3.950 | 2.930 | 1.900 | 0.690 | 0.000 | 0.000 | 0.000 | 0.000 |
| LTA U2 | 6.000 | 6.600 | 7.520 | 8.720 | 9.540 | 9.870 | 10.290 | 10.460 | 10.510 | 10.390 | 10.250 | 10.050 |
| LTA U3 | 6.000 | 6.070 | 6.480 | 7.240 | 7.340 | 6.980 | 6.640 | 5.900 | 4.940 | 3.760 | 2.480 | 0.980 |
| ATL U0 | 6.000 | 6.840 | 7.990 | 9.350 | 10.520 | 11.170 | 11.960 | 12.630 | 13.280 | 13.920 | 14.570 | 15.290 |
| ATL U1 | 6.000 | 6.840 | 7.990 | 9.350 | 4.680 | 1.410 | 0.660 | 0.240 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | |
| | CO2 Concentrations | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 353.000 | 370.660 | 390.520 | 413.510 | 439.140 | 465.690 | 492.830 | 520.570 | 548.810 | 577.500 | 606.720 | 636.680 |
| LTA U1 | 353.000 | 366.600 | 375.420 | 384.260 | 391.420 | 394.750 | 394.620 | 390.840 | 383.980 | 378.120 | 373.300 | 369.210 |
| LTA U2 | 353.000 | 370.110 | 388.460 | 409.490 | 432.410 | 455.300 | 477.840 | 499.820 | 520.800 | 540.250 | 558.210 | 574.720 |
| LTA U3 | 353.000 | 368.950 | 384.100 | 400.740 | 417.490 | 432.210 | 444.750 | 454.510 | 460.790 | 463.110 | 461.380 | 455.360 |
| ATL U0 | 353.000 | 370.650 | 390.470 | 413.400 | 439.010 | 465.600 | 492.740 | 520.490 | 548.740 | 577.430 | 606.650 | 636.610 |
| ATL U1 | 353.000 | 370.650 | 390.470 | 413.400 | 426.050 | 420.290 | 412.580 | 404.830 | 397.320 | 391.050 | 385.790 | 381.260 |
| | | | | | | | | | | | | |
| | Temperature Change | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 0.000 | 0.190 | 0.350 | 0.510 | 0.680 | 0.850 | 1.020 | 1.190 | 1.350 | 1.510 | 1.660 | 1.810 |
| LTA U1 | 0.000 | 0.350 | 0.600 | 0.780 | 0.930 | 1.030 | 1.100 | 1.120 | 1.110 | 1.060 | 1.010 | 0.970 |
| LTA U2 | 0.000 | 0.360 | 0.660 | 0.930 | 1.200 | 1.460 | 1.710 | 1.950 | 2.170 | 2.380 | 2.580 | 2.750 |
| LTA U3 | 0.000 | 0.180 | 0.320 | 0.450 | 0.570 | 0.690 | 0.790 | 0.870 | 0.930 | 0.970 | 0.990 | 0.980 |
| ATL U0 | 0.000 | 0.190 | 0.350 | 0.510 | 0.680 | 0.850 | 1.020 | 1.190 | 1.350 | 1.510 | 1.660 | 1.810 |
| ATL U1 | 0.000 | 0.370 | 0.670 | 0.950 | 1.210 | 1.340 | 1.370 | 1.350 | 1.310 | 1.250 | 1.190 | 1.130 |
| | | | | | | | | | | | | |
| | Value of Carbon Emission Rights | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 0.000 | 7.960 | 13.370 | 16.520 | 23.370 | 31.110 | 39.260 | 50.270 | 62.630 | 76.780 | 92.330 | 108.440 |
| LTA U1 | 0.000 | 142.030 | 193.350 | 225.860 | 301.030 | 352.510 | 419.760 | 473.030 | 459.710 | 469.310 | 483.150 | 497.460 |
| LTA U2 | 0.000 | 22.230 | 35.610 | 42.410 | 59.330 | 77.150 | 96.070 | 120.180 | 148.370 | 180.330 | 212.970 | 247.800 |
| LTA U3 | 0.000 | 55.910 | 86.990 | 105.580 | 148.350 | 187.230 | 230.650 | 282.440 | 335.240 | 393.100 | 449.650 | 513.020 |
| ATL U0 | 0.000 | 8.300 | 13.950 | 17.240 | 23.410 | 30.980 | 39.350 | 50.260 | 62.610 | 76.820 | 92.340 | 108.450 |
| ATL U1 | 0.000 | 8.300 | 13.950 | 17.240 | 397.750 | 402.090 | 455.070 | 460.640 | 459.710 | 469.310 | 483.150 | 497.460 |

**MERGE:**

CO2 Emissions

| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LTA U0 | 5.864 | 6.664 | 7.692 | 9.342 | 11.137 | 12.999 | 15.487 | 14.274 | 13.061 | 11.534 | 9.693 | 7.853 |
| LTA U1 | 5.864 | 5.830 | 5.730 | 5.723 | 4.962 | 4.043 | 0.770 | 0.462 | 0.154 | 0.000 | 0.000 | 0.000 |
| ATL UO | 5.864 | 6.663 | 7.686 | 9.332 | 11.136 | 13.005 | 15.493 | 14.281 | 13.071 | 11.544 | 9.702 | 7.861 |
| ATL U1 | 5.864 | 6.663 | 7.686 | 9.332 | 7.805 | 5.949 | 2.404 | 1.442 | 0.481 | 0.000 | 0.000 | 0.000 |

CO2 Concentrations

| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LTA U0 | 353.000 | 372.171 | 393.257 | 417.934 | 447.442 | 481.757 | 521.911 | 561.110 | 592.365 | 616.448 | 633.040 | 642.373 |
| LTA U1 | 353.000 | 370.466 | 386.095 | 400.379 | 412.219 | 420.124 | 419.489 | 412.693 | 406.341 | 400.282 | 394.907 | 390.301 |
| ATL U0 | 353.000 | 372.164 | 393.243 | 417.902 | 447.412 | 481.770 | 521.980 | 561.231 | 592.534 | 616.664 | 633.286 | 642.636 |
| ATL U1 | 353.000 | 372.164 | 393.243 | 417.902 | 440.609 | 454.751 | 457.575 | 452.382 | 445.181 | 436.751 | 428.907 | 422.289 |

Temperature Change

| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LTA U0 | 0.000 | 0.167 | 0.351 | 0.551 | 0.773 | 1.017 | 1.284 | 1.567 | 1.848 | 2.112 | 2.351 | 2.561 |
| LTA U1 | 0.000 | 0.330 | 0.678 | 1.028 | 1.373 | 1.701 | 1.986 | 2.206 | 2.364 | 2.480 | 2.567 | 2.635 |
| ATL U0 | 0.000 | 0.167 | 0.351 | 0.551 | 0.772 | 1.017 | 1.284 | 1.567 | 1.849 | 2.113 | 2.353 | 2.563 |
| ATL U1 | 0.000 | 0.167 | 0.351 | 0.551 | 0.947 | 1.500 | 1.975 | 2.351 | 2.631 | 2.836 | 2.983 | 3.090 |

Value of Carbon Emission Rights

| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LTA U0 | 0.000 | 6.351 | 9.288 | 13.183 | 18.239 | 24.276 | 32.462 | 51.601 | 70.741 | 100.617 | 141.228 | 181.84 |
| LTA U1 | 0.000 | 134.564 | 206.766 | 303.922 | 430.889 | 582.026 | 790.314 | 874.188 | 958.062 | 1387.115 | 2161.346 | 2935.577 |
| ATL U0 | 0.000 | 6.616 | 9.726 | 13.904 | 18.221 | 24.248 | 32.426 | 51.548 | 70.670 | 100.529 | 141.125 | 181.720 |
| ATL U1 | 0.000 | 6.616 | 9.726 | 13.904 | 471.340 | 653.286 | 918.924 | 1202.618 | 1486.312 | 1858.730 | 2319.873 | 2781.015 |

| SLICE: | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Carbon Emissions | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 5.864 | 7.146 | 8.571 | 9.905 | 10.798 | 11.112 | 11.389 | 11.726 | 11.868 | 11.821 | 11.602 | 11.237 |
| LTA U1 | 5.864 | 6.150 | 6.293 | 7.063 | 7.520 | 7.619 | 7.750 | 7.980 | 8.143 | 8.251 | 8.315 | 8.351 |
| LTA U2 | 5.864 | 7.027 | 8.299 | 9.562 | 10.398 | 10.678 | 10.928 | 11.241 | 11.371 | 11.327 | 11.127 | 10.796 |
| LTA U3 | 5.864 | 6.475 | 7.072 | 8.028 | 8.627 | 8.795 | 8.975 | 9.243 | 9.406 | 9.472 | 9.458 | 9.381 |
| ATL U0 | 5.864 | 7.141 | 8.559 | 9.859 | 10.798 | 11.112 | 11.389 | 11.726 | 11.868 | 11.821 | 11.602 | 11.237 |
| ATL U1 | 5.864 | 7.141 | 8.559 | 9.859 | 7.505 | 7.584 | 7.710 | 7.937 | 8.101 | 8.209 | 8.274 | 8.310 |
| | | | | | | | | | | | | |
| | Carbon Concentrations | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 351.162 | 368.488 | 389.439 | 414.276 | 442.319 | 471.559 | 499.602 | 526.403 | 552.307 | 576.614 | 598.708 | 618.098 |
| LTA U1 | 351.162 | 368.488 | 385.499 | 401.662 | 419.520 | 437.698 | 454.752 | 470.904 | 486.620 | 501.672 | 515.895 | 529.190 |
| LTA U2 | 351.162 | 368.484 | 388.960 | 412.757 | 439.563 | 467.441 | 494.106 | 519.536 | 544.085 | 567.104 | 588.031 | 606.426 |
| LTA U3 | 351.162 | 368.336 | 386.480 | 405.458 | 426.607 | 448.350 | 468.938 | 488.518 | 507.523 | 525.582 | 542.398 | 557.758 |
| | | | | | | | | | | | | |
| | Temperature Change | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 0.000 | 0.115 | 0.247 | 0.398 | 0.570 | 0.759 | 0.956 | 1.151 | 1.336 | 1.511 | 1.674 | 1.822 |
| LTA U1 | 0.000 | 0.156 | 0.334 | 0.524 | 0.716 | 0.915 | 1.118 | 1.317 | 1.510 | 1.696 | 1.875 | 2.044 |
| LTA U2 | 0.000 | 0.156 | 0.334 | 0.535 | 0.761 | 1.009 | 1.273 | 1.540 | 1.802 | 2.057 | 2.300 | 2.528 |
| LTA U3 | 0.000 | 0.115 | 0.246 | 0.388 | 0.536 | 0.691 | 0.849 | 1.004 | 1.150 | 1.289 | 1.420 | 1.541 |
| | | | | | | | | | | | | |
| | Value of Carbon Emission Rights | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 0.000 | 5.025 | 6.874 | 9.104 | 11.706 | 14.598 | 17.812 | 21.430 | 25.509 | 30.198 | 35.746 | 42.514 |
| LTA U1 | 0.000 | 61.270 | 82.251 | 106.754 | 134.395 | 163.467 | 193.316 | 223.295 | 251.616 | 278.428 | 295.558 | 306.390 |
| LTA U2 | 0.000 | 8.590 | 11.710 | 15.475 | 19.864 | 24.712 | 30.057 | 35.997 | 42.532 | 49.757 | 57.844 | 67.025 |
| LTA U3 | 0.000 | 36.704 | 49.563 | 64.584 | 81.565 | 99.571 | 118.225 | 137.161 | 155.407 | 171.984 | 185.735 | 195.223 |
| ATL U0 | 0.000 | 3.024 | 6.873 | 9.103 | 11.705 | 14.596 | 17.810 | 21.428 | 25.508 | 30.197 | 35.744 | 42.512 |
| ATL U1 | 0.000 | 5.024 | 6.873 | 9.103 | 137.407 | 166.524 | 196.441 | 226.432 | 254.711 | 279.468 | 298.583 | 309.482 |

| YOHE: | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | CO2 Emissions | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 5.864 | 7.251 | 8.519 | 9.833 | 11.065 | 12.195 | 13.243 | 14.175 | 15.024 | 15.774 | 16.459 | 17.074 |
| LTA U1 | 5.864 | 6.609 | 6.027 | 5.866 | 5.796 | 5.771 | 5.917 | 6.164 | 6.513 | 6.897 | 7.312 | 7.718 |
| ATL UO | 5.864 | 7.141 | 8.345 | 9.343 | 11.056 | 12.269 | 13.305 | 14.239 | 15.074 | 15.823 | 16.495 | 17.108 |
| ATL U1 | 5.864 | 7.141 | 8.345 | 9.343 | 6.027 | 5.027 | 5.258 | 5.649 | 6.069 | 6.504 | 7.034 | 7.551 |
| | | | | | | | | | | | | |
| | Value of Carbon Emission Rights | | | | | | | | | | | |
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
| LTA U0 | 0.000 | 1.740 | 4.180 | 8.070 | 11.460 | 15.070 | 19.210 | 23.460 | 28.010 | 32.430 | 36.840 | 40.920 |
| LTA U1 | 0.000 | 24.500 | 58.960 | 120.730 | 163.200 | 198.130 | 226.810 | 247.240 | 263.570 | 275.660 | 286.400 | 295.840 |
| ATL U0 | 0.000 | 2.860 | 6.920 | 13.710 | 11.080 | 14.840 | 18.920 | 23.300 | 27.800 | 32.360 | 36.760 | 40.950 |
| ATL U1 | 0.000 | 2.860 | 6.920 | 13.710 | 210.490 | 238.440 | 256.980 | 272.090 | 284.500 | 287.580 | 290.800 | 293.470 |