Using Decision Theory To Rank Energy Choices For An Uncertain Future

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Section 1, The Situation Today

Global warming and climate change, peak oil and population growth; it is evident the world is in crisis. Can humanity find the natural resources and the energy it needs to sustain itself beyond this century? Will the planet remain a congenial host to our species, or will its favor chill to us, casting us into a dry, minor Ice Age bankrupt of fossil hydrocarbon fuel?

Planners, policymakers and thoughtful citizens are looking into the future, trying to devise intelligent strategies to deal with the looming global changes. They observe the melting of glaciers and tundras, the breakup of ancient Antarctic ice sheets, the intensifying ferocity of tropical storms, the expansion of deserts, the accelerating demise of many animal species from plankton and frogs to fish and polar bears.

Equally evident is the stagnation and even reversal of human development to end world poverty. Astounding inequities, gross injustices, wars, plagues, shameless exploitation of the young, weak, sick, poor and female; all show beyond dispute that human society has yet to develop a consciousness beyond the merely tribal, beyond the narrowest of clan, class and ethnic loyalties.

How do we choose energy technologies to power our human societies in the future, given these realities? And, who is it that decides, that allocates the benefits and costs?

We are faced with major uncertainties. Nature presents us with the immense challenge of global warming. With every year of greater waste heat accumulation in the biosphere, there is an increased probability of the steady thermodynamic state of the world -- what we call climate -- abruptly shifting to the new equilibrium of an Ice Age. This might be triggered if the thermohaline cycle, which moves tropical ocean heat to high latitudes, collapses due to the falling salinity of polar oceans, caused by polar melt. The measured salinity of the North Atlantic has dropped steadily since 1960. Can you imagine the territory of the United States shifted from one with much fertile land, good sources of fresh water and a temperate climate, to a cold and windy desert and near-desert, within your lifetime? This is a real possibility. (1)

Aside from Nature's challenge, we face those generated by our immaturity as a species, our seeming inability to organize human society on bases of social responsibility, cooperation, compassion and economic equity. One need only review the Millennium Development Goals published by the United Nations in 2000 to realize how little, in actuality, we have advanced. (2), (3), (4) (See Appendix 1)

So, we must expect the incidence of international terrorism and "asymmetrical warfare" to increase in frequency and success. The systems of energy generation and distribution in the advanced and prosperous nations are potential targets of terrorist attack. In this regard, the ultimate popular fear is "nuclear terrorism," a catastrophe on the scale of Chernobyl or the Hiroshima and Nagasaki bombings brought about by a terrorist group.

Let us focus all these anxieties into a general question we can then analyze, as follows. Given the uncertain probabilities of abrupt climate change brought on by global warming, and the incidence of major terrorist attacks, how do we rank the possible choices for a national investment in energy technology between renewables, coal and nuclear?

Section 2, Analysis Based On Decision Theory

The analysis presented in this report is based on decision theory, which will be explained as it is being applied to our question.

Ranking based on the estimation of benefit-to-cost ratios (BCR) is a commonly used approach, so why not use it here? BCR analysis works well to differentiate between possible actions whose individual features and consequences can be converted into finite dollar amounts. For example, in the design deliberations by an automotive engineering team, the various features of a proposed vehicle can be assigned reasonable BCR values. Engines, transmissions, brakes, air conditioners, leather upholstery and safety devices can each be assigned a cost based on manufacturing expenses, the potential extent of the liability should they fail, and their projected burdens to the environment that become the responsibility of the manufacturer. The benefits of these components would be the dollar equivalents to efficiencies of manufacture; the expected dollar equivalents of the reliability, safety and economy a buyer can anticipate, as well as the "sales appeal" they add to the vehicle; and the dollar equivalents to insurance-by-design against public (e.g., environmental) liabilities.

BCR analysis becomes muddy when a potential action has the possibility of leading to an infinitely desirable or undesirable consequence. What is the BCR of a wager based on Russian Roulette? What is the BCR to a suicide bomber? What is the BCR of becoming a parent? What is the BCR to starting a war? What is the BCR of falling in love? What is the BCR to an organ donor? In contemplating global warming triggered climate change (GWCC) and nuclear terrorism (NT), we are faced with possible consequences that are difficult to equate to mere quantities of currency. In the language of decision theory, BCR analysis is effective when there are no poles in the desirability matrix.

Decision theory allows for subjectivity in expressing preference and in estimating probabilities, and refined aspects of the theory allow for the evolution of preference as new information becomes available during the course of deliberations. These features allow decision theory to produce definite conclusions even when considering consequences of "infinite" cost or benefit. An additional, and very attractive, feature of decision theory is that its mathematical implementation is very simple.

We can think of decision theory as a method to become clear about "what to do," and BCR analysis as a method to optimize our activities to implement our chosen goal, the "how to do it."

Section 3, An Introductory Example

The introduction of decision theory as a formal study (in epistemology, a branch of philosophy) is credited to Thomas Bayes, an 18th century English mathematician. Since Bayes, decision theory has been refined by many, notably Frank Plumpton Ramsey (1931), John von Neumann and Oskar Morgenstern (1947), and Richard C. Jeffrey (1965). (5)

The *agent* must decide between several identified *actions*, under a set of mutually exclusive possible *conditions*, leading to a matrix of potential *consequences*. The agent will have preferences regarding these consequences, and these are called *desirabilities*. Each possible action will have an *expected desirability*, which is the sum of the products of the desirability and probability for each of its possible consequences. The best action will be that with the largest expected desirability, and the list of possible actions is ranked on the basis of their expected desirabilities, also called the *utilities*.

The agent seeks to travel from Las Pulgas to San Francisco. Ticket cost is equal, and the only consideration is travel time; the agent wishes to minimize it. The train makes the trip in 8 hours. The airplane makes the trip in 3 hours if the weather is clear in San Francisco, and 15 hours when it is fogged in. The agent consults a weather forecast and decides the probability of fog in San Francisco will be the fraction p (choose a number between 0 and 1). Which trip is quicker?

The agent forms a desirability matrix for the actions and conditions given,

$$\begin{array}{lll} & \text{fog} & \text{no fog} \\ \text{plane} & -15 & -3 \\ \text{train} & -8 & -8. \end{array}$$

The negative of the travel times are taken as numerical desirabilities (in this case, undesirabilities). Note, actions are rows; conditions are columns.

The probability matrix is given as

$$\begin{array}{lll} & \text{fog} & \text{no fog} \\ \text{plane} & p & 1-p \\ \text{train} & p & 1-p. \end{array}$$

Notice that in this case the probabilities of the conditions (fog or no fog) are independent of the courses of action. It is quite possible to face decisions in which the probabilities for the occurrence of conditions depend on the course of action chosen.

The expected desirabilities here are:

$$\begin{array}{llcl} \text{plane} & -15p + -3(1-p) & = & -12p - 3 \\ \text{train} & -8p + -8(1-p) & = & -8. \end{array}$$

Corresponding entries in the desirability and probability matrices are multiplied (this is *not* matrix multiplication as in linear systems), and the products are summed along each row (action).

The expected desirabilities of plane and train travel are equal when

$$\begin{array}{rcl} -12p - 3 & = & -8 \\ p & = & 5/12. \end{array}$$

So, for $p < 5/12$ take the plane, and for $p > 5/12$ take the train.

Expected desirabilities, or utilities, limited to the range of 0 to 1 can be convenient. To that end, the following theorem is useful.

The linear transformation of multiplying each element in a desirability matrix by a positive constant *a*, and then adding a constant *b*, produces an equivalent desirability matrix, in that it will produce the same ranking of actions as the original desirability matrix.

For example, using a = 1 and b = 8,

$$\begin{matrix} -15a + b & -3a + b \\ -8a + b & -8a + b \end{matrix} \quad \text{--->} \quad \begin{matrix} -7 & 5 \\ 0 & 0 \end{matrix}$$

Forming the expected desirabilities from the equivalent desirability matrix and the original probability matrix gives

plane $\quad -7p + 5(1-p) = -12p + 5$

train $\quad 0p + 0(1-p) = 0.$

Again, neutrality occurs when the probability of fog is p = 5/12.

A map of utility-probability space shows how ranking varies with probability.

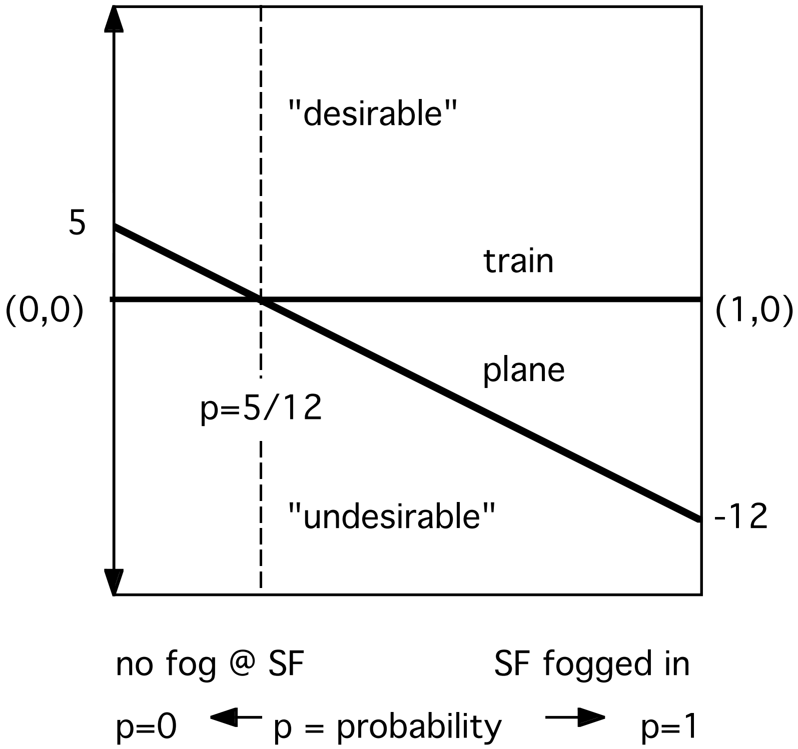


Figure 1, Expected desirabilities of trips by plane or train, given the probability of fog at San Francisco. [-12 should be -7]

Section 4, Energy, Climate Change and Nuclear Terror

We seek to rank three courses of action, which we label:

R = renewables,

C = coal,

N = nuclear.

We are faced with two simultaneous sets of conditions, characterized as:

"security"	versus	"terrorism,"
"global warming" (GW)	versus	"climate change" (GWCC).

"Security" and "global warming" refer to conditions similar to those today continuing into the future, while "terrorism" and "climate change" indicate the extreme (undesirable) possibilities occur (i.e., "it" will or "it" won't happen).

Consequence and probability matrices can be:

Security D-matrix	*security*	*terror*
renewables	Clean & safe; need minding	Fairly safe
coal	Messy and cumbersome	Vulnerable
nuclear	Expensive and dangerous	Catastrophe

Security P-matrix	*security*	*terror*
R	(1 - pr)	(pr)
C	(1 - pc)	(pc)
N	(1 - pn)	(pn)

Climate D-matrix	*GW*	*GWCC*
R	Low CO2; needs minding	Safe power
C	Hotter and dirtier world	Catastrophe
N	Low CO2; expensive and dangerous.	Have power, need security

Climate P-matrix	*GW*	*GWCC*
R	(1-p)	(p)
C	(1-p)	(p)
N	(1-p)	(p)

The probabilities in the security D-matrix depend on the course of action. This allows for the possibility that terrorism targeting energy infrastructure can be encouraged or discouraged by our selection of its type.

On the other hand, we discount that a selection of energy technology will influence Nature one way or the other on GWCC, basically we assume that it is too late. If you do not like this assumption, then just use a new climate p-matrix similar to the security p-matrix, with three GWCC probabilities depending on course of action, say *qr, qc and qn.* Some believe that use of coal would more quickly drive us to GWCC, thus $qr \sim qn << qc$.

Now, we must assign desirabilities to possible consequences, and construct utility-probability maps to see how rankings depend on the probabilities; and we must consider the *simultaneous* impact of security and GW conditions.

To proceed, we must first clarify who the agent is (section 5), and then we must describe how this agent can arrive at a desirability matrix, rationally (section 6).

Section 5, Who Decides?

The choice of a national investment is taken by a controlling elite. The cost of that investment is drawn from the public resources of the nation, so as the citizenry pay they will have opinions on the matter.

For the purposes of the present study, the political realities of the world are simplified to an "80/20" model: political power and economic wealth are concentrated within an elite 20% of the population, the remaining 80% are a dependent population of workers.

Think of the 80% as those for whom the Millennium Development Goals are most important; who aspire to have (or are fortunate to enjoy) national health and education programs, and for whom income is gained by selling their labor, produce and crafts. The 20% are the elite who manage the operations of governments, militaries and economies; who accumulate wealth by financial transactions; and for whom existing energy technologies and economic conditions are assets and positions to be protected and enhanced.

The stratification of society described crudely here as the 80/20 model has been called the "democratic deficit" in reference to the United States and Europe. We do not debate the fact of social stratification here, we simply note it, and account for it in our Bayesian deliberation on energy for human development.

Section 6, Preference Rankings Of Energy Technologies

The discussion in this section is entirely a construction of my own, it is not a procedure taken from decision theory, nor is it presented as anything other than an *ad hoc* exercise to organize thinking about our specific question. There are refinements of formal decision theory that tease out "accurate" subjective desirabilities and subjective probabilities from an initial subjective ranking of possible actions. And, one uses objective desirabilities (as in BCR analysis) and objective probabilities if they are known. But, one must begin somewhere, and then subsequent work, new insights and data can lead to improving the analysis.

We start by making subjective judgments about the R, C and N technologies. "We," in this case are two agents, A80 and A20, representatives of our social profile. Six factors are considered:

1, *Nuclear* threat potential,

2, *Global* warming contribution,

3, *Small* scale and local control possible, or does it require high capitalization controlled by remote interests?

4, *Security* of the energy grid against physical attack, reliability of supply,

5, *Subsidy* required?

6, does it contribute to *military* power?

We can construct a table of subjective judgments about the objective features of each energy technology; and we can assign numbers to these subjective reactions, arbitrarily, as shown.

**Table, Characterization of 6 Features For R, C, N;
and Subjective Votes**

#	[<R>	A80	A20]	[<C>	A80	A20]	[<N>	A80	A20]
1	[0	1	1]	[0	1	1]	[high	0	0]
2	[low	1	1]	[high	0	0]	[low	1	1]
3	[local	1	0]	[remote,	0	1]	[remote,	0	1]
4	[high	1	1]	[some,	0.5	0]	[low	0	0]
5	[some,	1	0]	[high	0	1]	[high	0	1]
6	[low	1	-1]	[high	0	1]	[high	0	1]
total	[	A80	A20]	[	A80	A20]	[	A80	A20]
votes	[<R>	6	2]	[<C>	1.5	4]	[<N>	1	4]

The initial preference ranking for A80 is (R, C, N) = (6, 1.5, 1); and for A20 it is (N, C, R) = (4, 4, 2). We do not compare numbers between A80 and A20, they are taken to be on independent arbitrary scales. What we do compare are the rankings, notice the opposition between the agents on the preferences for N and R; also notice that A20 has equal affections for C and N.

At this point we return to the formal Bayesian analysis (continue from section 4).

Section 7, Expected Desirabilities For Energy Under Attack

The desirability matrices for A80 and A20 can now be specified, based on the "subjective votes" of preference each agent expressed in section 6. You will note that as a matter of consistency (and sanity), for any action the desirability of a "terror" consequence is always lower than that of a "security" outcome.

A80 Security D-matrix

A80-NT-D	*security*	*terror*
R	6	-1
C	1.5	-1.5
N	1	-6

A20 Security D-matrix

A20-NT-D	*security*	*terror*
R	2	-2
C	4	-4
N	4	-4

We form equivalent D-matrices with (a=1/6, b=0) for A80, and (a=1/4, b=0) for A20.

A80 Security D'-matrix

A80-NT-D	*security*	*terror*
R	1	-1/6
C	1/4	-1/4
N	1/6	-1

A20 Security D'-matrix

A20-NT-D	*security*	*terror*
R	1/2	-1/2
C	1	-1
N	1	-1

The security P-matrix, with dependent probabilities is

Security P-matrix	*security*	*terror*
R	(1 - pr)	(pr)
C	(1 - pc)	(pc)
N	(1 - pn)	(pn)

and the three expected desirabilities for each of A80 and A20 are

A80 Expected Desirabilities	
R	(6 - 7pr)/6
C	(1 - 2pc)/4
N	(1 - 7pn)/6

A20 Expected Desirabilities	
R	(1/2) - pr
C	1 - 2pc
N	1 - 2pn

Figure 2 shows the utility-probability spaces for A80 and A20. Note that probabilities *pr, pc* and *pn* all lie along the horizontal axis.

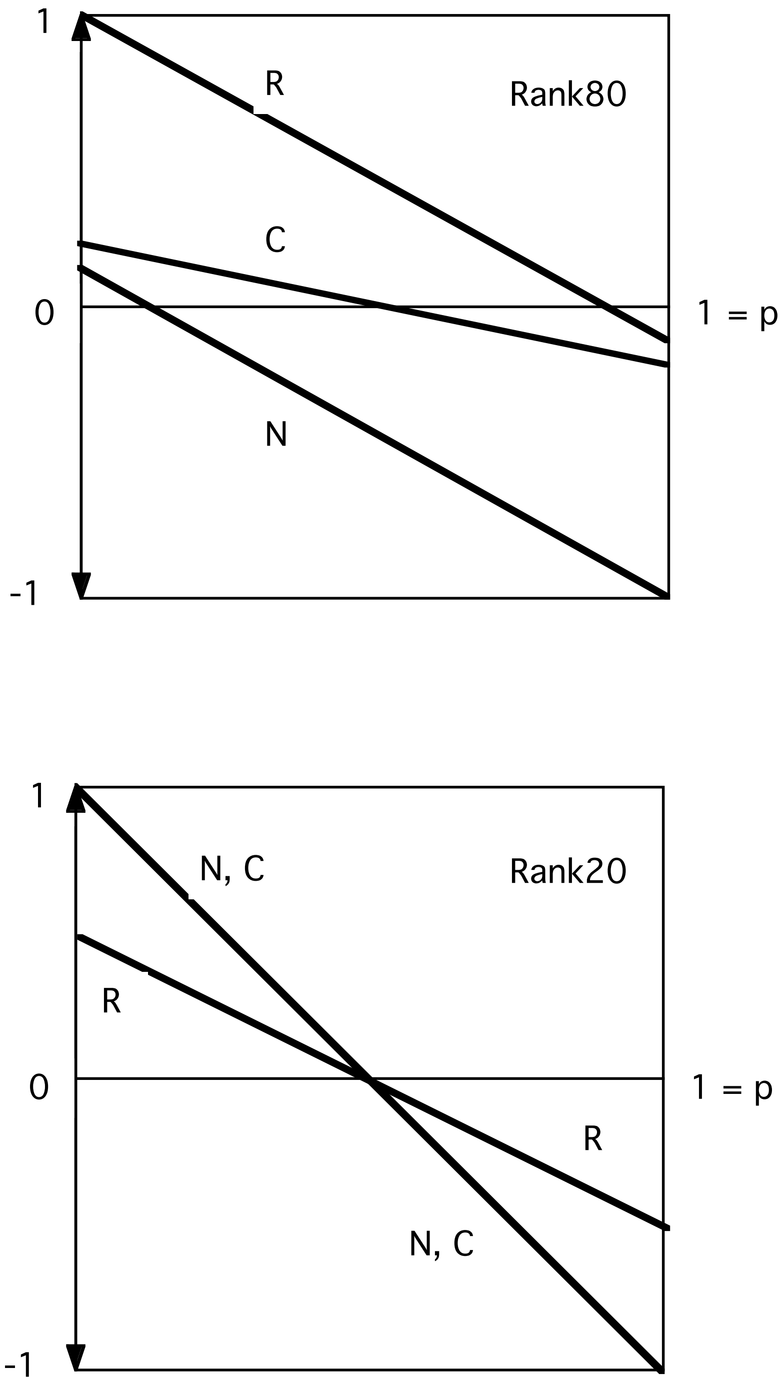


Figure 2, Rankings (expected desirabilities of R, C and N) at given probabilities (pr, pc, pn) of terrorist success

We observe that A80 generally prefers R over C or N, and would do so until the unlikely extreme of pr ~ 1, and pc ~ pn ~ 0; that is to say nuclear and coal technologies are always free of terrorist attack, while renewable technology suffers if continuously.

A20's preference for N and C over R will only change when uniform terrorism has greater than 50% success (pr = pc = pn > 0.5), or when N and C technologies suffer a much higher incidence of successful terrorist attack than R (pr ~ 0, pc ~ pn > 1/4).

The rankings for both A80 and A20 converge to (R, C, N) under conditions of continuous warfare, where pr, pc and pn are all over 1/2.

Section 8, Expected Desirabilities For Energy In Climate Change

The desirability matrices for A80 and A20 under conditions of global warming are found in the same way as for the security conditions.

A80 GW D-matrix

A80-GW-D	*GW*	*GWCC*
R	3	0
C	1.5	-6
N	1	-1

A20 GW D-matrix

A20-GW-D	*GW*	*GWCC*
R	-2	-2
C	4	-4
N	4	4

We form equivalent D-matrices with (a=1/6, b=0) for A80, and (a=1/4, b=0) for A20.

A80 GW D'-matrix

A80-GW-D	*GW*	*GWCC*
R	1/2	0
C	1/4	-1
N	1/6	-1/6

A20 GW D'-matrix

A20-GW-D	*GW*	*GWCC*
R	-1/2	-1/2
C	1	-1
N	1	1

The GW P-matrix, with independent probabilities is

GW P-matrix	*GW*	*GWCC*
R	(1 - p)	(p)
C	(1 - p)	(p)
N	(1 - p)	(p)

and the three expected desirabilities for each of A80 and A20 are

A80 Expected Desirabilities

R	(1 - p)/2
C	(1 - 5p)/4
N	(1 - 2p)/6

A20 Expected Desirabilities

R	-1/2
C	1 - 2p
N	1

Figure 3 shows the utility-probability spaces for A80 and A20 under conditions of global warming.

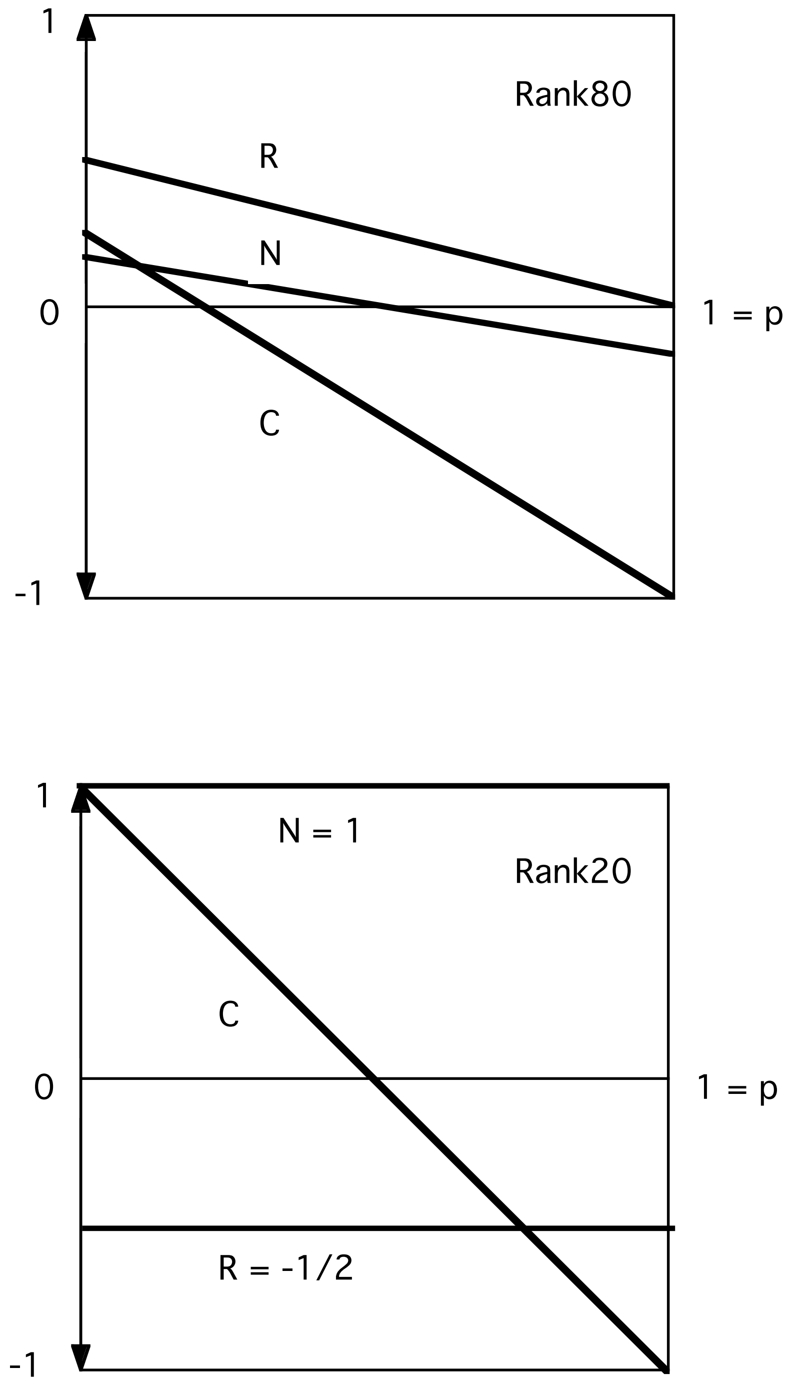


Figure 3, Rankings (expected desirabilities of R, C and N) at a given probability of abrupt climate change.

The ranking for A80 is (R, C, N) for $p < 1/11$, then (R, N, C) till $p = 1$. The ranking for A20 is (N, C, R) for $p < 3/4$, and (N, R, C) thereafter. Note that A20 has unwavering expected desirabilities for N and R, the former highly desired and the latter not esteemed. One can visualize GW situations with dependent probabilities *qr, qc* and *qn*, from Figure 3.

The consideration of global warming splits out the tie between N and C in A20's initial preference ranking. Both agents agree in rapidly discounting the utility of C, as the probability of severe GWCC increases. However, the two agents remain in conflict as to the leading preference under any GW outcome; A80 prefers R and A20 prefers N.

Section 9, Ranking Regions In Climate-Terror Probability 2-Space

What rankings occur when we consider the simultaneous occurrence of security (NT) and global warming (GW) conditions? To simplify the discussion (and graphics), we will consider the probabilities to be independent of our actions ($pr = pc = pn$, and $qr = qc = qn$).

We define a probability 2-space, with the probability for insecurity as the vertical axis, and the probability for GWCC as the horizontal axis. For each of A80 and A20, we map regions of different ranking as shown in Figure 4.

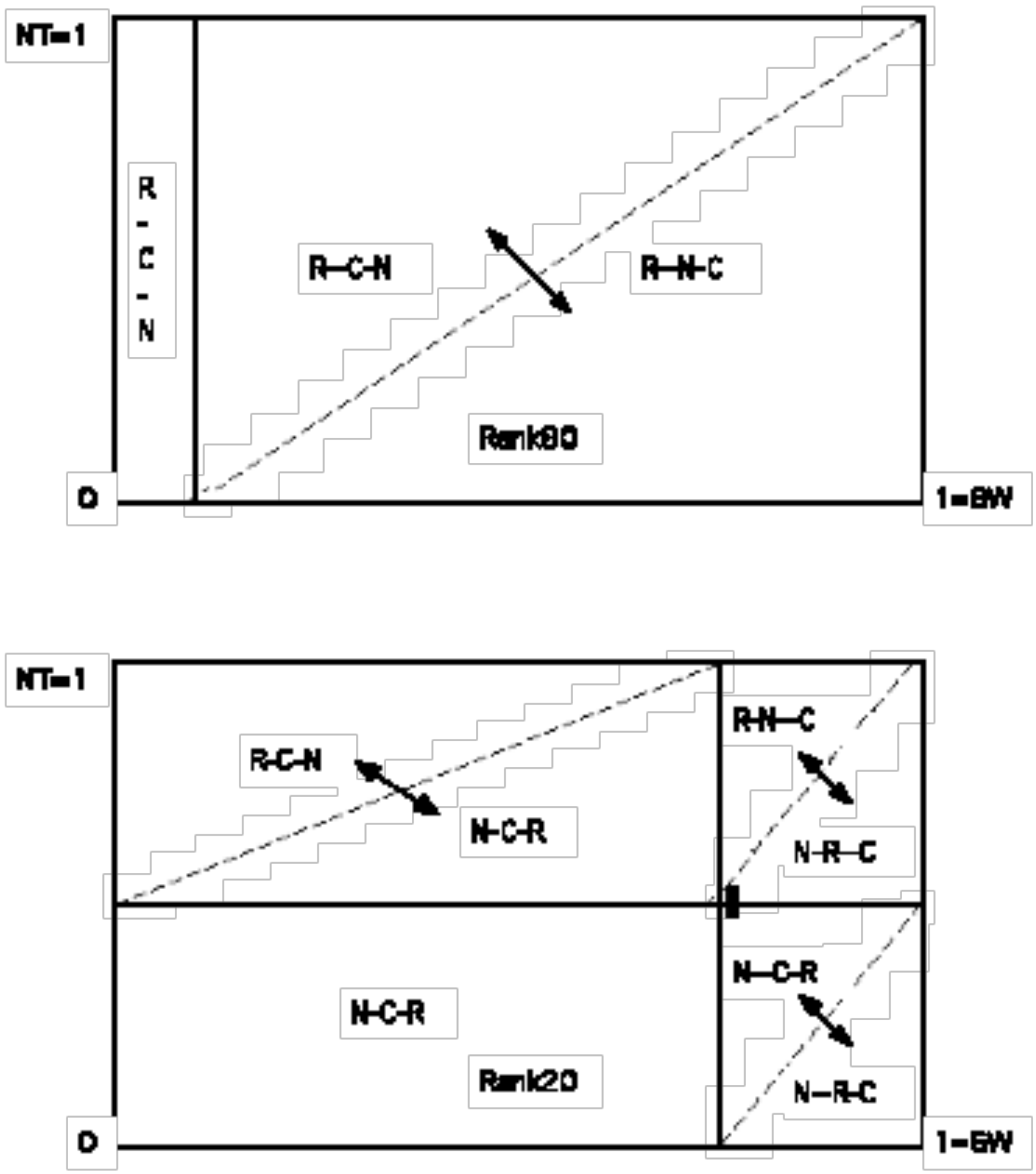


Figure 4, Rankings, in "Climate-Terror" probability space; "N-Terror" is vertical and GWCC is horizontal

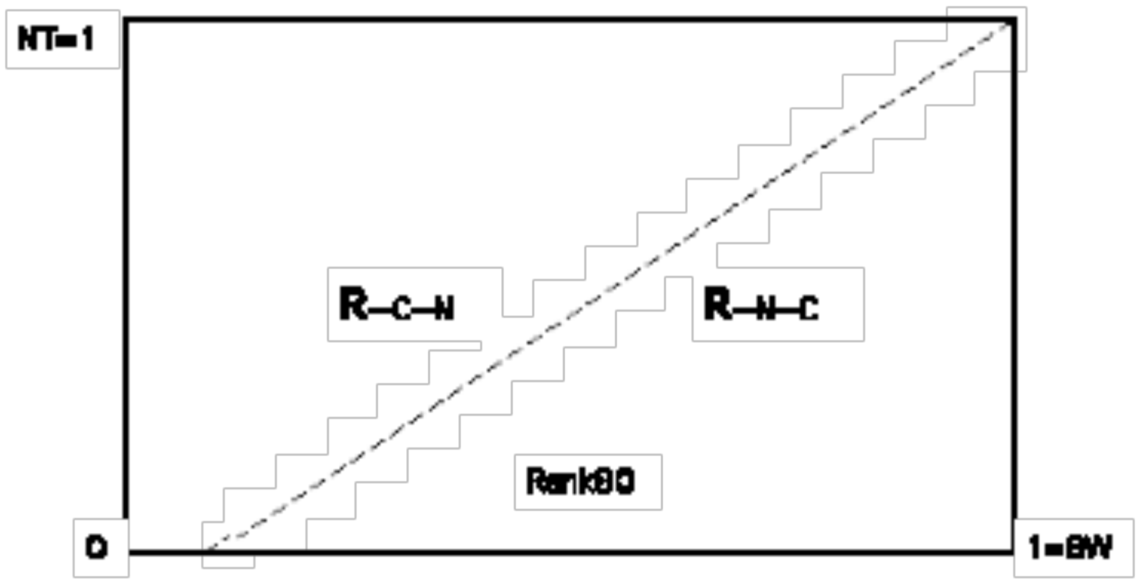
We use NT as a label for the probability of "terror," and GW as a label for the probability of global warming triggered climate change (GWCC). This is for ease of interpreting Figures 4 and 5.

A map for A80's division of NT-GW probability 2-space is shown as the top rectangle. A corresponding map for A20's ranking division of probability 2-space is shown below. Boundaries defined by our results are shown as solid lines, and boundaries whose existence is implied by our results are shown as dashed lines.

A80 always prefers R technology. A80 has a preference ranking of (R, C, N) for all NT until GW = 1/11; for larger GW it shifts from (R, C, N) to (R, N, C). The exact boundary along which the shift occurs could be determined by a more advanced application of decision theory. However, we can infer that the boundary must be close to the dotted line shown because N should be least preferred at point (NT, GW) = (1, 0), while C should be least preferred at point (NT, GW) = (0, 1). Radii drawn from these points to sweep out zones of exclusion for N and C, respectively, would meet near the dotted diagonal.

The map for A20 is more intricate. There is a well-defined preference for (N, C, R) between the origin and (NT, GW) = (1/2, 3/4). Three implied boundaries between ranking regions are shown.

If we were to squint our analytical eye when interpreting Figure 4, we might see a more cohesive picture, though admittedly less rigorously defined. Figure 5 shows such a view, where boundaries are dissolved between regions of identical ranking (and a touch of artistic license is allowed).



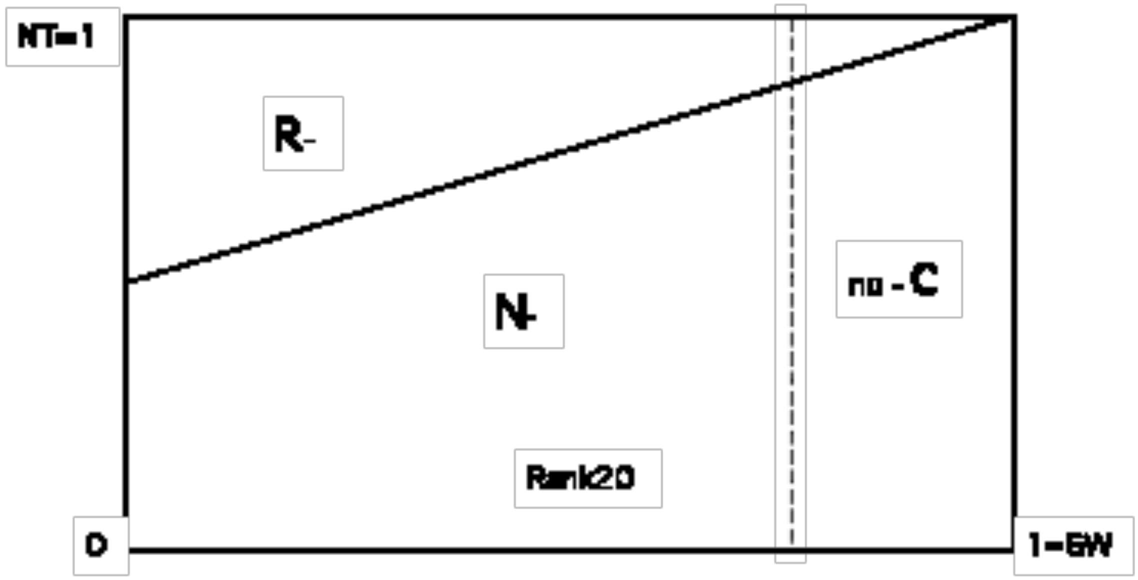


Figure 5, Rankings generalized across "Climate-Terror" probability space; note regions of R or N dominance.

It is clear from Figure 5 that A80 always prefers R, and only considers C and N technologies as extremes of NT alone or GW alone, respectively, are approached.

The "squint picture" of A20's p-space map is quite clear. N is preferred for p-space below a line connecting (NT, GW) = (1/2, 0) and (NT, GW) = (1, 1); R is preferred above, where NT > 1/2. Beyond GW = 3/4, C is the least preferred option.

We can see that above A20's boundary of (leading) preference for N, both agents agree that R is best. Similarly, beyond GW = 3/4, both agents agree C is the worst. But, conflict exists over most of p-space, bounded by the origin, GW < 3/4 and NT < (1/2 to ~1); A80 wants R and A20 wants N.

How will this conflict be resolved? Perhaps political activity by A20's class or A80's class will influence a change of preference -- a change of subjective consensus -- on the part of the other class, and a general social unity formed as to the ranking of energy technology options. Or, perhaps the opposition on energy choices will contribute to a political change. The need for decision may be so great as to change the nature of the decider.

Section 10, Comparing With "Common Sense" And Reality

We can compare the results of a decision theory analysis with "common sense" and with objective reality.

If there are no logical or procedural errors in our model, then a disagreement with "common sense" would simply mean that our actual preferences are different from those used in the model. This point should be obvious after comparing results for agents A80 and A20. The value of the theory is in making plain how subjectivities lead to specific conclusions. This can focus discussion between negotiating agents on the key "value judgments" at the root of their disagreement on selecting what would otherwise appear to be a logical course of action.

Comparison with reality is possible after the fact, one simply observes how the actual course of events either vindicates or repudiates the action selected. This method of testing decision theory can offer little comfort in situations like those we are considering, which can involve catastrophic terrorism and environmental collapse.

Another way to validate a decision theory analysis is to find work published by others, whose subjectivities are clearly stated, and which duplicates decision theory results by other means. In the case of agent A80, an analog in reality can be found; it is the New Economic Foundation (NEF). This economic "think-and-do tank" has issued very detailed reports on energy development choices. (6), (7)

Besides the many charts, graphs, tables and pictures in the NEF report comparing the utilities of R and N technologies, there is a chart (Figure 3 in reference 6) showing a measured preference among the public (in the UK) of 80% for renewables, while under 20% for nuclear -- if both were priced equally. [8]

BCR analysis appears in the NEF report as a bar chart of cost-per-kWh for nuclear, several renewables, micro-renewables and combined-heat-and-power (CHP) technologies (Figure 5 in reference 6). There is extensive discussion of each technology's features and liabilities, which must be turned into monetary costs for BCR analysis. Thus, there is a thorough critique of nuclear power, including discussion of construction costs, security (terrorism) and insurance. Another interesting BCR comparison is a bar chart of cost-per-tonne of carbon saving, several renewable technologies having negative costs!

The NEF report concludes with a proposed "energy assessment grid" (Table 5 in reference 6), that is something like the table of subjective votes in section 6 of our report. Recall that our subjective votes were numerical values assigned to the specific manner each technology exhibited a set of six objective factors. The NEF identifies nine factors, and based on its economic studies scores them for each technology on a 0 to 5 point scale.

The NEF's proposed energy assessment grid (it is incomplete) can be seen as a basis from which to begin a decision theory analysis (construct desirability matrices), and it can also be seen as a formation approaching the concept of an expected desirability (utility).

Because of the general agreement on results between the NEF study and the decision analysis with A80 subjectivities, and because of the complete difference in means of analysis, this English economics-of-energy research helps to make our decision analysis credible.

Section 11, Coal Versus Nuclear, China Versus the USA, A20s Collide

The single largest source of CO2 emission is the United States, 4.5% of the world's population produces over 24% of world CO2 emissions. The most likely potential source of comparable magnitude in the immediate future is China, burning its coal to raise the per-capita electrical energy consumption of its people (1484 kWh/c in 2002, versus 13,456 kWh/c for the USA; c = capita), and its economic gross domestic product (GDP). Today, China has 21% of global population and produces 12% of global CO2 emissions.

As an average, each American consumes 9 times more electrical power than a Chinese individual, and consequently produces 9 times as much CO2. Americans release CO2 at 5.3 times the average world per capita emission, while the Chinese release at 0.57 times the average global per capita emission.

If the Chinese were to consume 3084 kWh/c, they would equal America's total electrical energy consumption and CO2 emissions, and the ratio of American to Chinese per capita use and emission would be 4-to-1 (alternatively, the projected use and emission of 4 Chinese would equal that of 1 American). However, the global emissions of CO2 would be minimally 12% above today's quantity.

Clearly, China has the potential to become the largest national source of CO2 emissions.

In order for US A20s to convince Chinese A20s that a change to nuclear power is best, they will have to address the primary Chinese concern about any energy technology: producing the energy "now."

Let us introduce a new agent to our analysis, a member of China's 20% class, called A20C. Also, we add a seventh factor to our list of section 6, this being the *preparation time* of an energy technology. This time is the unavoidable interval between the decision to build new energy plants and the beginning of useful production. This interval is taken up by the paperwork tasks of permits and financing, by actual construction, and by assembly of the workforce.

The characterization of the preparation time for R, C and N, as well as the subjective votes on this by A80, A20 and A20C might be as follows.

preparation time:

USA R, C, N = low, high, high,
China R, C, N = low, low, high;

subjective votes:

A80 R, C, N = (1, 0, -1)
A20 R, C, N = (0, 0, 0)
A20C R, C, N = (1, 1, -1)

total subjective votes (assume A20C = A20 on previous 6 factors):

A80 R, C, N = (7, 1.5, 0)
A20 R, C, N = (2, 4, 4)
A20C R, C, N = (3, 5, 3).

The Bayesian deliberation could be the following.

D-matrices for security and their equivalents are:

D80,	7	0	-->	1	0
	1.5	-1.5	-->	3/14	-3/14
	0	-7	-->	0	-1.
D20,	2	-2	-->	1/2	-1/2
	4	-4	-->	1	-1
	4	-4	-->	1	-1.
D20C,	3	-3	-->	3/5	-3/5
	5	-5	-->	1	-1
	3	-5	-->	3/5	-1.

Expected desirabilities for NT (security versus p=terrorism) are:

	ED80	ED20	ED20C
R	1-p	(1/2)-p	(3-6p)/5
C	(3-6p)/14	1-2p	1-2p
N	-p	1-2p	(3-8p)/5.

There is little change in the NT outlook of A80, and none in that of A20 (see Figure 2). As there will be no change in A20's GW outlook (votes were 0), and A80's additional vote for R can only reinforce A80's preference for R under any circumstances, we only need to find A20C's GW outlook to complete the exercise. Begin with A20C's GW desirability matrix (which is different from the one for security).

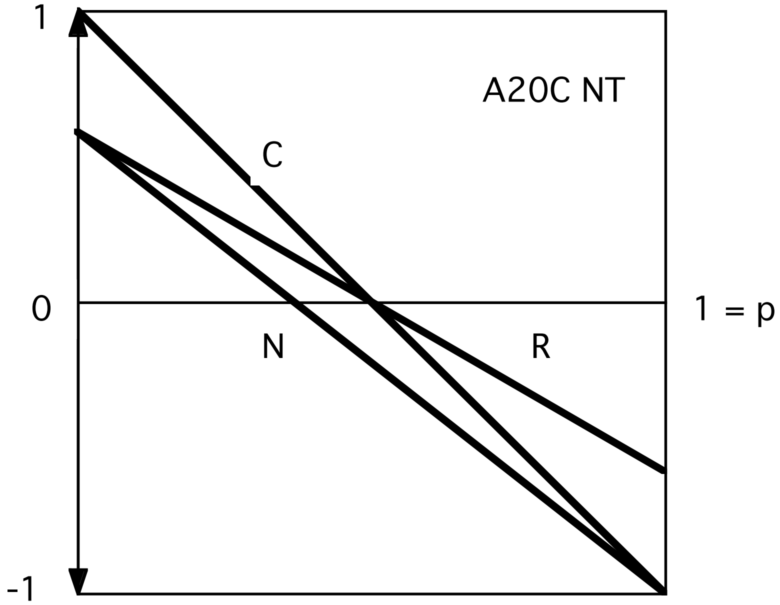
$$\text{DGW20C,}\quad \begin{array}{cccccc} 3 & 3 & \quad & \text{-->} & \quad & 3/5 \quad 3/5 \\ 5 & -5 & & \text{-->} & & 1 \quad -1 \\ 3 & 3 & & \text{-->} & & 3/5 \quad 3/5. \end{array}$$

A20C expected desirabilities for GW (GW versus q=GWCC)

	EDGW20C
R	3/5
C	1-2q
N	3/5.

The utility-probability maps for A20C, for both NT and GW, are shown in Figure 6.

Both maps show that A20C has a strong preference for coal because it is a readily available source of power. A20C is well aware of global warming, as the lower map shows, and it is also evident that A20C welcomes any source of energy, as can be seen by the steady esteem for R and N as the desirability of C wanes with the increased prospect of GWCC.



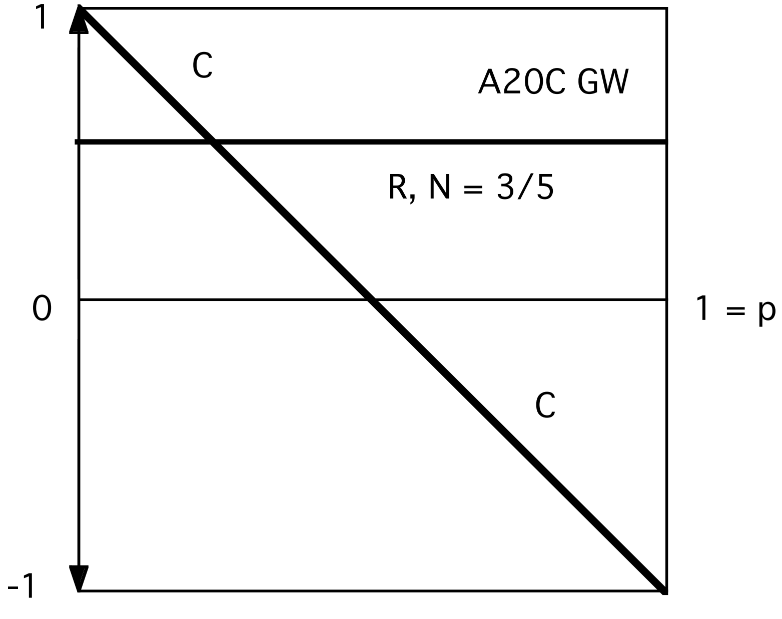
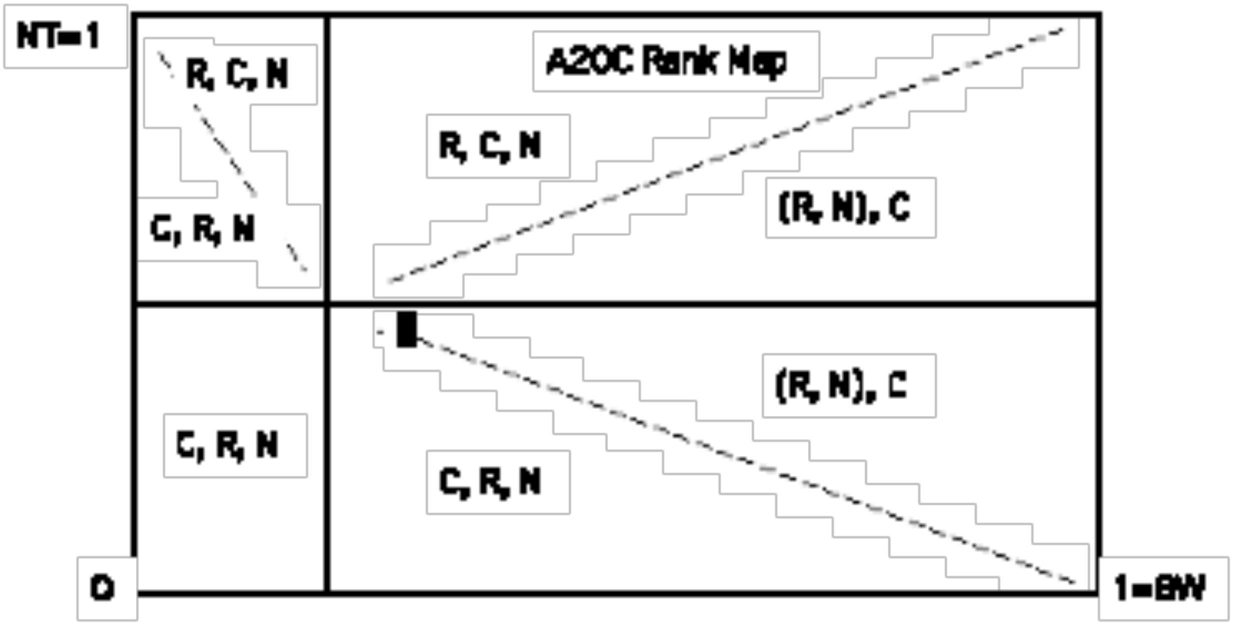


Figure 6, A20C utility-probability maps for NT (top) and GW (below)

The layout of A20C's outlook over the climate-terror probability 2-space is shown in Figure 7.



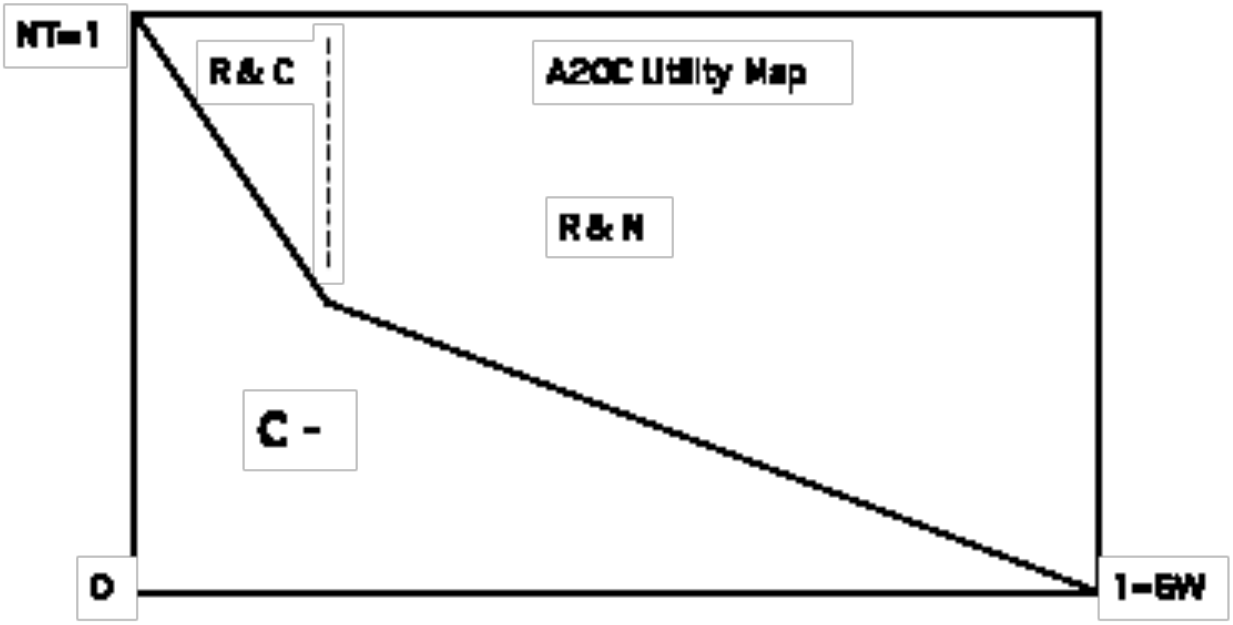


Figure 7, A20C climate-terror probability 2-space, ranking and utility maps.

A20C sees coal as the source of China's power in the immediate future, because the availability of energy is the overriding concern (low preparation time). As A20C judges that GWCC is becoming more likely (q, or "GW" > 1/5) then the development of R and N will displace the reliance on coal. The boundary line can be interpreted as: at a higher likelihood of GWCC, it will take less terrorism to make A20C give up coal; at a low likelihood of GWCC, no amount of terrorism can make A20C give up coal.

One need only compare Figure 5 and Figure 7 to see the basic conflict of outlook between A20 and A20C. Also, this conflict could be enhanced if A20 and A20C make different "assumptions" about just what the probability of GWCC is. By "assumption" I mean not just the scientific probability of the occurrence of GWCC based on climate models, but also the value judgments an agent makes as to the possible impact of such an event on their society.

Section 12, Summary Of Conclusions

If the totality of investment in energy (the sum of users' purchases and public subsidies) were to be redistributed among R (renewable), C (coal) and N (nuclear) sources, because of the expected depletion of the world's oil, and the uncertainties regarding physical security (terrorism and warfare) and a drastic climate change triggered by global warming during the next decade or two, what would be the best course of action?

1, For the majority of people anywhere (>80%), the best choice is R (renewables). Read the report cited in reference 6.

2, For the minority (<20%) who prize concentrated power and wealth above the Millennium Development Goals (see Appendix 1), the best choice is:

  i, N (nuclear) if HDI > 0.9 and level (USA HDI = 0.944);

  ii, (a), C (coal) if HDI < ~0.84 and climbing (China HDI = 0.755),
  (b), N (nuclear) if HDI > ~0.84 (which occurs at 3084 kWh/c);

3, Fossil liquid fuel is essential to military power, and nuclear power is highly desirable. The military's physical power is used for rapid mobility (fighting vehicles and troop transport) and force concentration (munitions and armor; bases, large ships and submarines). A ranking of technologies to accomplish each is:

  i, rapid mobility:

    (a), oil (refined liquid fuels),
    (b), synthetic oil (from coal and natural gas);

ii, force concentration:

(a), nuclear (for electricity, mechanical power and weapons),
(b), petroleum and chemicals (munitions, non-metallic armor),
(c), coal (for a static energy grid, or "Titanic"-era propulsion),
(d), metals (armor; not a source but an industrial energy sink).

Appendix 1, The Millennium Development Goals

At the turn of the century, the United Nations hosted a conference to develop a set of world development goals to guide the membership's efforts. These Millennium Development Goals (MDG) were identified as follows:

1, eradicate extreme poverty and hunger;

2, achieve universal primary education;

3, promote gender equality and empower women;

4, reduce child morality;

5, improve maternal health;

6, combat HIV/AIDS, malaria and other diseases;

7, ensure environmental sustainability;

8, develop a global partnership for development.

Clearly, the best types of energy technologies for the future are those that help achieve the Millennium Development Goals. (2) The United Nations Development Programme supports projects to make energy services available to poor communities, to help them develop a higher standard of living as measured by the Human Development Index (HDI). (3) These goals engage the efforts of people in the technically advanced and economically prosperous nations as well, because today's world is too small not to feel the impact of distant poverty. (4) The three reports cited here, by the UN and the government of the United Kingdom, are both instructive and inspiring. As a matter of simple physical and economic fact, poverty can be eliminated.

Appendix 2, "1% On 2% For 100%," Solar Power USA

Solar power at 1% conversion efficiency on 2% of the land area of the USA would produce the total national electrical energy use of 4 x 10^12 kWh/year.

E = 4 x 10^12 kWh/yr = (13,456 kWh/c) x (297 x 10^6 c), (c = capita = person).

P = 1000 W/m^2 = 1kW/m^2 = 10^6 kW/km^2 = solar influx (an average).

Hours/year = 8766 (@ 365.25 days/year).

Daylight hours/year = (1/2)(hours/yr) = 4383 hours.

Estimate of shading, clouds, obscuring weather, sun angle = 1/2,

Estimated annual clear insolation = S =

= (10^6 kW/km^2)(4383 hr)(1/2)
= 2.192 x 10^9 (kWh/yr)/km^2

Area required for E = A = E/S = (4 x 10^12)/(2.192 x 10^9) = 1825 km^2,

Area A could be a square of linear extent r = (A)^(1/2) = 42.7 km.

Area required *to recover* E if *conversion efficiency* = *e*, is A/e:

e = 10%, A/e = 1.83 x 10^4 km^2, --> r = (A/e)^(1/2) = 135 km,

e = 1%, A/e = 1.83 x 10^5 km^2, --> r = (A/e)^(1/2) = 427 km,

(1 km = 0.6137119 mile).

US land area = US = 9,631,418 km^2 = 5,984,685 mi^2.

Fraction of land area at a given e is f = (A/e)/US:

e = 100%, f = 1.9 x 10^-2 %

e = 10%, f = 1.9 x 10^-1 %

e = 1%, f = 1.9 %.

Number of Sites @ e To Recover E = 4 x 10^12 kWh/yr.

# sites 1%	# sites 10%	# sites 100%	r (square) km	r (square) mi
1	-	-	427	262
3	-	-	247	152
10	1	-	135	83
30	3	-	78	48
100	10	1	43	26
300	30	3	25	15
1000	100	10	14	8.3

One can easily imagine that US military bases cover more than a few percent of the US land area, and they could be covered in solar collection and conversion systems (of many types) to supply the national electrical energy needs. Beat your swords into solar panels.

Endnotes

[1] Manuel Garcia, Jr., "Thirsty Invaders, Chasing Heat," *Swans*, 19 July 2004, http://www.swans.com/library/art10/mgarci18.html

[2] "The Energy Challenge for Achieving the Millennium Development Goals," UN-Energy, 22 July 2005, http://esa.un.org/un-energy/pdf/UN-ENRG%20paper.pdf

[3] "Energizing the Millennium Development Goals, A Guide to Energy's Role in Reducing Poverty," United Nations Development Programme (UNDP), August 2005, http://www.undp.org/energy/docs2/ENRG-MDG_Guide_all.pdf

[4] "Energy for the Poor: Underpinning the Millennium Development Goals," Department For International Development, Government of the United Kingdom, August 2002, ISBN-1-86192-490-9, http://www.dfid.gov.uk/pubs/files/energyforthepoor.pdf

[5] Richard C. Jeffrey, *The Logic Of Decision*, McGraw-Hill Book Company, NY: 1965

[6] "Mirage and Oasis -- Energy Choices In An Age Of Global Warming," New Economics Foundation (NEF), June 2005, ISBN-1-904882-01-3, http://www.neweconomics.org

[7] "The Price Of Power -- poverty, climate change, the coming energy crisis and the renewable revolution," New Economics Foundation (NEF), 2004, ISBN-1-899407-86-3, http://www.neweconomics.org

[8] I will not ask the reader to believe that I found this chart after working out the examples of this report, but it is true.