# Energy Choices For An Uncertain Future

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GIVEN: World energy crisis

FIND:

1. What are the choices?
2. What are the risks?
3. Who decides?
4. What can we expect?

METHOD:

Apply *decision theory* to supply quantified answers.

*What is decision theory?*

A specialty in epistemology -- a branch of philosophy.

Introduced by Thomas Bayes, an 18th century English mathematician (Bayesian statistics).

Expanded by:

economists (Frank Plumpton Ramsey, 1931),

mathematicians (John von Neumann and Oskar Morgenstern, 1947)

and logicians (Richard C. Jeffrey, 1965). (1)

*Why use decision theory?*

Facing outcomes (*consequences*) of:

uncertain probability, and

inestimable cost.

Examples:

Global warming triggering an abrupt climate change -- collapse of the thermohaline cycle initiating a new Ice Age. (2)

"Nuclear terrorism," the exploitation of nuclear fuel and waste, and energy infrastructure for terrorism and war. (3)

*Why not use Benefit-to-Cost Ratio (BCR) analysis -- a sound economic technique?*

"Infinitely" costly and "infinitely" lasting liabilities muddy BCR analysis:

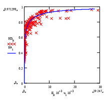
nuclear power is "uninsurable" (World Bank, Swiss Re) (4),

collapse of marine food chain due to ocean acidification by $CO_2$ would be an "inestimable" loss. (5)

Yet clearly, we will continue to use both fossil and nuclear power.

*What is the best choice based on BCR?*

> On a straightforward BCR analysis -- *including all costs and subsidies* -- renewable energy technologies combined with conservation are the most beneficial alternatives for most of humanity. (4)



Human Development Index (HDI) and Electricity Use per Capita (kWh/c)

Data from 177 nations; 40 kWh/c < E < 29,247 kWh/c (6), (7)

| # | HDI | Country | kWh/c | Popul. | CO2 |
|---|---|---|---|---|---|
| 10 | .944 | U.S.A. | 13,456 | 4.5% | 24.4% |
| 85 | .755 | China | 1,484 | 21% | 12.1% |
| | | | | “%” of world | |

The HDI Climb and the Energy Ladder -- First World

*Evolution of Highly Industrialized Nations:*

Coal -- industrialized in 19th century,

Oil -- transition in early 20th century as a highly industrialized state,

Nuclear -- sustain high industrialization in mid and late 20th century,

*Transition awaiting* -- to post-nuclear, post-fossil fuel state, without loss of HDI.

The HDI Climb and the Energy Ladder -- Second World

*Evolution of States Industrializing Now:*

Coal & Oil -- industrializing in the 20th and early 21st centuries,

*skip the First World's "Atomic Age," and leap-frog to*

post-nuclear, post-fossil fuel, high HDI state, in mid to late 21st century.

The HDI Climb and the Energy Ladder -- Third World

*Evolution of Non-Industrialized Nations:*

move up the "energy ladder," (8):

crop waste & dung ->

wood ->

charcoal ->

kerosene ->

liquefied petroleum gas (LPG) ->

ethanol & methanol ->

*skip the First World's 19th & 20th centuries, leap-frog to*

local renewable sources (low capitalization), gridless and micro-grid distribution (9), to achieve =>

sustainable development to meet the *Millennium Development Goals.* (8)

Basic Decision Theory: best *action* within uncertain *conditions*

Example, *Trip from Las Pulgas to San Francisco.*

*consequence matrix*, in hours:

| | *Conditions* | |
|---|---|---|
| *Actions* | fog @ SF, | clear @ SF |
| plane | 15 hours | 3 hours |
| train | 8 hours | 8 hours |

*desirability matrix*, using hours:

| | fog @ SF, | clear @ SF |
|---|---|---|
| plane | -15 | -3 |
| train | -8 | -8 |

*probability matrix*:

| | fog @ SF, | clear @ SF |
|---|---|---|
| plane | p | 1-p |
| train | p | 1-p |

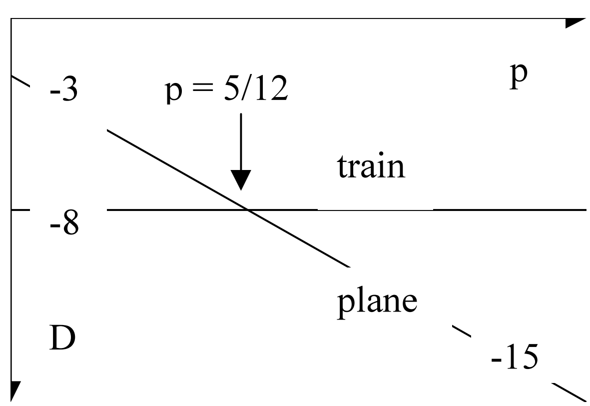
Best action has the highest *utility*, or *expected desirability*.

*Utility* = sum of products of corresponding probabilities and desirabilities:

| | | | | |
|---|---|---|---|---|
| U(plane) | = | -15p + -3(1-p) | = | -12p-3 |
| U(train) | = | -8p + -8(1-p) | = | -8. |

*Ranking:*

| | | |
|---|---|---|
| p < 5/12, | take the plane, | U(plane) > U(train) |
| p = 5/12, | indifferent, | U(plane) = U(train) |
| p > 5/12, | take the train, | U(train) > U(plane). |



Energy, Climate Change and Security

| *GWCC consequences* | | GW | GWCC |
|---|---|---|---|
| Renewables = | R | Low GW; chores | Safe power |
| Coal = | C | Hot dirty world | Catastrophe |
| Nuclear = | N | Low GW; $, danger | Power; safe? |

| *GWCC probabilities* | GW | GWCC |
|---|---|---|
| R | 1-qr | qr |
| C | 1-qc | qc |
| N | 1-qn | qn |

| *Security outcomes* | Security | Terror |
|---|---|---|
| R | Safe | Fairly safe |
| C | Cumbersome | Vulnerable |
| N | Expensive danger | Catastrophe |

| *Security probabilities* | Security | Terror |
|---|---|---|
| R | 1-pr | pr |
| C | 1-pc | pc |
| N | 1-pn | pn |

Three Viewpoints on Energy: *Desirabilities by A80, A20, A20C*

| *Security* | A80 | | A20 | | A20C | |
|---|---|---|---|---|---|---|
| | safe | terror | safe | terror | safe | terror |
| R | 1 | 0 | 1/2 | -1/2 | 3/5 | -3/5 |
| C | 3/14 | -3/14 | 1 | -1 | 1 | -1 |
| N | 0 | -1 | 1 | -1 | 3/5 | -1 |

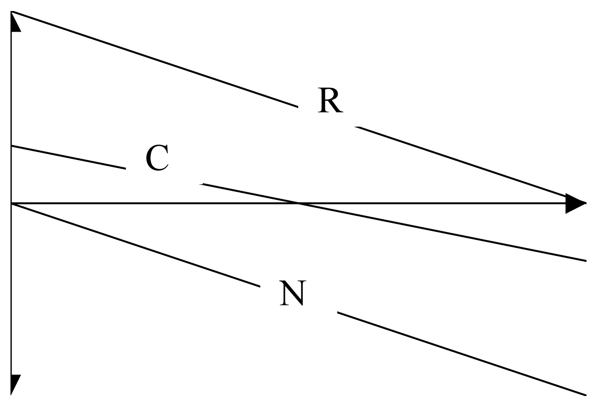
| *GWCC* | A80 | | A20 | | A20C | |
|---|---|---|---|---|---|---|
| | GW | GWCC | GW | GWCC | GW | GWCC |
| R | 1/2 | 0 | -1/2 | -1/2 | 3/5 | 3/5 |
| C | 3/14 | -1 | 1 | -1 | 1 | -1 |
| N | 0 | -2/7 | 1 | 1 | 3/5 | 3/5 |

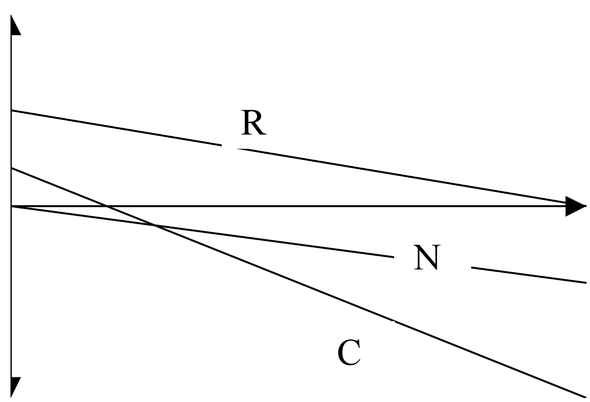
Utilities for A80, A20 and A20C on Security & GWCC

| *Security* *(p = pr, pc, pn)* | A80 | A20 | A20C |
|---|---|---|---|
| R | 1-p | (1/2)-p | (3-6p)/5 |
| C | (3-6p)/14 | 1-2p | 1-2p |
| N | -p | 1-2p | (3-8p)/5 |

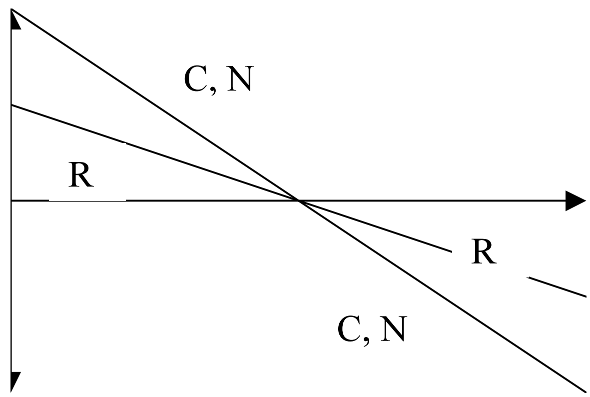
| *GWCC* *(q = qr, qc, qn)* | A80 | A20 | A20C |
|---|---|---|---|
| R | (1-q)/2 | -1/2 | 3/5 |
| C | (3-17q)/14 | 1-2q | 1-2q |
| N | -2q/7 | 1 | 3/5 |

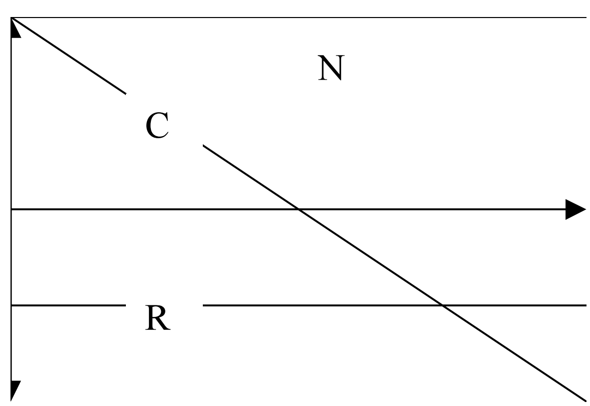
Ranking at Probability, Security & GWCC -- A80



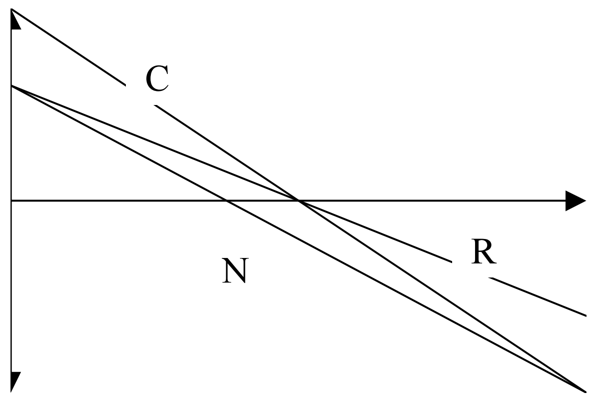



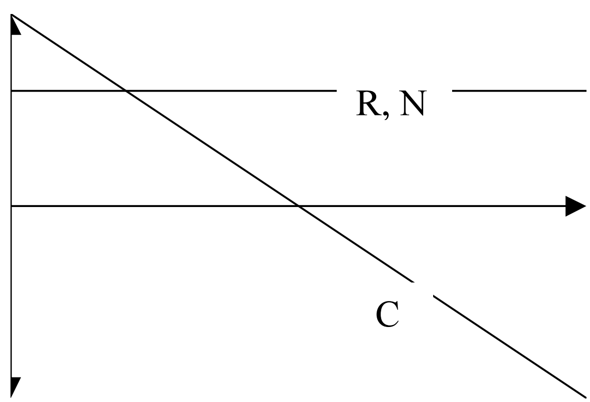
Ranking at Probability, Security & GWCC -- A20



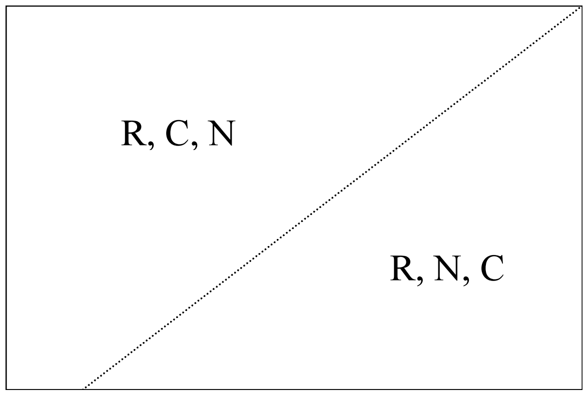
Ranking at Probability, Security & GWCC -- A20C

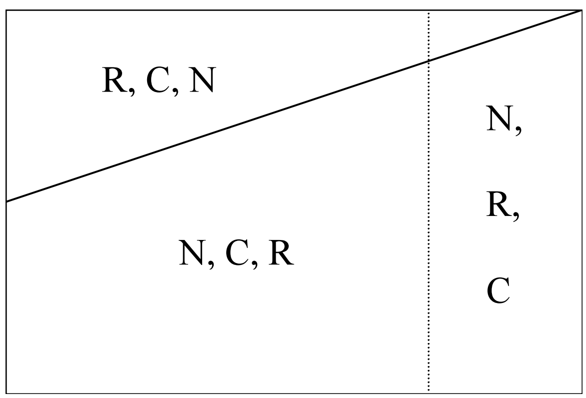


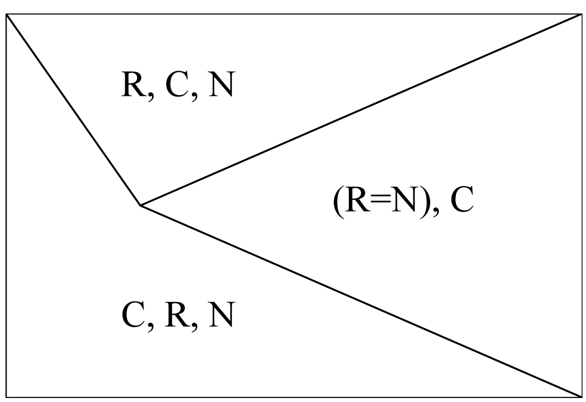



Ranking Maps in Probability 2-Space: A80, A20, A20C

*(vertical: p = terror; horizontal: q = GWCC)*



Ranking of actions depends on:

logically possible actions,

potential outcomes,

character of the agent.

Improve on the basic theory:

1, more rigorous way to determine desirabilities,

2, account for variation of agent outlook (character),

3, consider multiple actions (e.g., RC, CN),

4, consider simultaneous conditions (GW & terror),

5, put ranking on a scale.

Logical Decision Theory (Richard C. Jeffrey)

*Actions* and *consequences* are combined into *propositions* that have both *probability* and *desirability*.

1. Consider four energy technologies: R, C, N, O; (O = oil).

2. Two actions, TRUE and FALSE, are possible for each of the four factors R, C, N, O:

   "X is TRUE" = X

   "X is FALSE" = $\underline{X}$

3. The range of possible action is set by the 16 logically exclusive & collectively exhaustive products of the 4 factors R, C, N and O;

   e.g., R$\underline{CNO}$ = R + not-C + not-N + not-O.

4. Possible outcomes include the *conjunction* (logical AND), *disjunction* (logical OR) and *negation* (logical NOT) of *propositions*;

   e.g., R V N, (R OR N; OR is "and/or"),

   RN (R AND N)

   $\underline{R\ V\ N}$ (NOT "R V N")

Logical Decision Theory (continued)

5. The *probability of any proposition* is the sum of the probabilities of the 4-products (*elements*) in which it is TRUE.

6. The *desirability of any proposition* is the probabilistic average of the desirabilities of the elements in which it is TRUE.

7. Once the *preference ranking* of the 16 elements is put on the proper scale (to be described) then a quantitative ranking of any list of propositions can be found.

*"Just give me a simple answer"*

OK, here it is:

Rank the four "power terms" below, and your ranking of energy technologies will be given by the corresponding letter codes:

| | | |
|---|---|---|
| R | <=> | MDG; power to end poverty (8), |
| C | <=> | Commercial power, |
| N | <=> | Political power, |
| O | <=> | Military power. |

## Preference Rankings at Uniform Probabilities

| Rank | DN "No Nuclear" | DW "No Warming" | DE "Energy Now" |
|---|---|---|---|
| 1 | R<u>CNO</u> | R<u>CNO</u> | <u>RCN</u>O |
| 2 | R<u>CN</u>O | R<u>C</u>N<u>O</u> | <u>R</u>C<u>N</u>O |
| 3 | RC<u>N</u>O | <u>RC</u>N<u>O</u> | RC<u>N</u>O |
| 4 | RC<u>NO</u> | <u>RCNO</u> | <u>R</u>C<u>NO</u> |
| 5 | <u>R</u>C<u>N</u>O | R<u>C</u>NO | RC<u>NO</u> |
| 6 | <u>R</u>C<u>NO</u> | RCN<u>O</u> | <u>R</u>CNO |
| 7 | <u>RCN</u>O | R<u>CN</u>O | RCNO |
| 8 | <u>RCNO</u> | <u>RC</u>NO | <u>R</u>CN<u>O</u> |
| 9 | RCNO | <u>R</u>CN<u>O</u> | RCN<u>O</u> |
| 10 | R<u>C</u>NO | RC<u>NO</u> | R<u>CN</u>O |
| 11 | RCN<u>O</u> | RCNO | R<u>C</u>NO |
| 12 | <u>R</u>CNO | RC<u>N</u>O | <u>RC</u>NO |
| 13 | R<u>C</u>N<u>O</u> | <u>R</u>CNO | R<u>C</u>N<u>O</u> |
| 14 | <u>RC</u>NO | <u>RCN</u>O | <u>RC</u>N<u>O</u> |
| 15 | <u>R</u>CN<u>O</u> | <u>R</u>C<u>N</u>O | R<u>CNO</u> |
| 16 | <u>RC</u>N<u>O</u> | <u>R</u>C<u>NO</u> | <u>RCNO</u> |

underscore = "Not"

Probability and Desirability Scales

1. Probabilities of the 16 elements sums to unity,

   $\Sigma p_n = 1,$ $\qquad$ $n = 1$ to 16.

2. Probability for any proposition (e.g., "R is true") is

   $prob(X) = \Sigma p_n,$ $\qquad$ $n$ for "X is true."

3. Desirabilities $D_n$ selected such that

   $\Sigma p_n D_n = 0,$ $\qquad$ $n = 1$ to 16.

4. Desirability for any proposition (e.g., "$\underline{C}N$ is true") is

   $des(X) = \Sigma p_n D_n / prob(X),$ $\qquad$ $n$ for "X is true."

5. "X or $\underline{X}$" is *always* true; its desirability is set to 0:

   $prob(X \vee \underline{X}) = 1,$ $\qquad$ $T = X \vee \underline{X},$

   $des(T) = \Sigma p_n D_n / prob(T) = 0,$ $\qquad$ all $n$

   "good" $\rightarrow$ $des(X) > des(T),$

   "bad" $\rightarrow$ $des(X) < des(T),$

   "indifferent" $\rightarrow$ $des(X) = des(T).$

"The Effective Agent" -- A Probability Model

1. Agents rank their preferences ($DN_n$, $DW_n$, $DE_n$, ...) assuming the 16 elements are uniform gambles ($p_n$ = 1/16).

2. A composite of these agents will have desirabilities

$$D_n = \alpha * DN_n + \beta * DW_n + \gamma * DE_n + \ldots,$$

$$1 = \alpha + \beta + \gamma + \ldots.$$

3. *Assume the composite agent has the power to act on its positive desirabilities, and to suppress the negative ones.*

4. Set new probabilities,

| | |
|---|---|
| $S = \Sigma(D_n > 0)$, | (sum positive desirabilities), |
| $p_n = D_n/S$, | $D_n > 0$, |
| $p_n = 0$, | $D_n < 0$. |

5. "Necessity," T, has changed as there are fewer elements, so recalibrate desirability scales (same procedure for all),

$$D_n(\text{new}) = D_n(\text{old}) - \Sigma p_n(\text{new}) D_n(\text{old}), \quad n = 1 \text{ to } 16.$$

6. Can now find the probability and desirability of *any* proposition (that can be formed from R, C, N, O and the *conjunction*, *disjunction* and *negation* operators).

Desirability scales used in the "character study."

Desirabilities with uniform probabilities were assumed to be:

1. evenly spaced,

2. within the range $-1000 < D < +1000$,

3. neither of these are *necessary*,

4. only $\Sigma p_n D_n = 0$ is necessary for any initial desirability profile.

Agent($\alpha$=0, $\beta$=1, $\gamma$=0), "Stop Global Warming"

| prob= | | des= |
|---|---|---|
| .234 | R$\underline{CNO}$ | 292 |
| .203 | R$\underline{C}$N$\underline{O}$ | 158 |
| .828 | $\underline{O}$ | 73 |
| .422 | $\underline{N}$ | 69 |
| .922 | $\underline{C}$ | 32 |
| .672 | R V C, R | 31 |
| .172 | $\underline{RC}$N$\underline{O}$ | 25 |
| .859 | R V N | 18 |
| 1.000 | T | 0 |
| .578 | N | -51 |
| .391 | RN | -60 |
| .328 | $\underline{R}$ | -64 |
| .141 | $\underline{RCNO}$ | -108 |
| .109 | R$\underline{C}$NO | -242 |
| .172 | O | -351 |
| .25 | C V O | -358 |
| .078 | RCN$\underline{O}$, CN, RC, C | -375 |
| .047 | R$\underline{CN}$O | -508 |
| .016 | $\underline{RC}$NO | -642 |

Agent($\alpha$=1/2, $\beta$=0, $\gamma$=1/2), "USA Today"

| prob= | | des= |
|---|---|---|
| .212 | RC$\underline{N}$O | 167 |
| .423 | CO | 106 |
| .192 | $\underline{R}$C$\underline{N}$O | 100 |
| .385 | RC | 53 |
| .692 | O | 41 |
| .712 | C | 37 |
| .173 | $\underline{RCN}$O | 33 |
| .500 | $\underline{R}$ | 23 |
| .981 | C V O, $\underline{N}$ | 9.8 |
| 1.000 | T | 0 |
| .827 | R V C | -7 |
| .500 | R V N, R | -23 |
| .154 | RC$\underline{NO}$ | -33 |
| .288 | $\underline{C}$ | -91 |
| .308 | $\underline{O}$ | -92 |
| .135 | $\underline{R}$C$\underline{NO}$ | -100 |
| .096 | R$\underline{CN}$O | -233 |
| .019 | RCNO, R$\underline{CNO}$, RN, CN, N | -500 |

Agent($\alpha$=0, $\beta$=1/2, $\gamma$=1/2), "Cut GW, & Energy Now"

| | | |
|---|---|---|
| prob= .500 | RC, C | des= 11 |
| .167 | $R\underline{C}N\underline{O}$, $RCN\underline{O}$, $RC\underline{NO}$, $\underline{RCN}O$, $RC\underline{N}O$, CO, CN, $\underline{R}$ | 11 |
| .75 | C V O | 3.7 |
| .583 | $\underline{N}$, $\underline{O}$ | 1.6 |
| 1.000 | T | 0 |
| .833 | R V N, R V C, R | -2.2 |
| .417 | N, O, RN | -2.2 |
| .500 | $\underline{C}$ | -11 |
| .083 | $R\underline{C}NO$, $R\underline{CNO}$ | -56 |

Agent(α=1/3, β=2/3, γ=0), "Cut GW, & Avoid Nuclear"

| | | |
|---|---|---|
| prob= .357 | $\mathrm{R\underline{CNO}}$ | des= 429 |
| .683 | $\mathrm{\underline{N}}$ | 141 |
| .762 | $\mathrm{\underline{O}}$ | 67 |
| .794 | R V C, R | 57 |
| .937 | $\mathrm{\underline{C}}$ | 32 |
| .849 | R V N | 26 |
| 1.000 | T | 0 |
| .151 | $\mathrm{\underline{RCNO}}$, $\mathrm{R\underline{CN}O}$ | -149 |
| .135 | $\mathrm{R\underline{C}N\underline{O}}$ | -194 |
| .238 | O | -214 |
| .206 | $\mathrm{\underline{R}}$ | -221 |
| .302 | C V O | -270 |
| .262 | RN | -278 |
| .317 | N | -303 |
| .087 | $\mathrm{R\underline{C}NO}$ | -327 |
| .056 | $\mathrm{\underline{RC}N\underline{O}}$ | -416 |
| .040 | $\mathrm{RCN\underline{O}}$, CN | -460 |
| .063 | RC, C | -477 |
| .024 | $\mathrm{RC\underline{NO}}$ | -505 |

Agent(α=1/3, β=1/3, γ=1/3), "Straight Average"

| | | |
|---|---|---|
| prob= .236 | RCNO | des= 85 |
| .417 | O | 46 |
| .208 | RCNO | 40 |
| .806 | R V N, R | 33 |
| .389 | RC | 19 |
| .903 | R V C | 15 |
| .514 | C | 11 |
| 1.000 | N, T | 0 |
| .181 | RCNO, RCNO | -4.3 |
| .486 | C | -12 |
| .306 | CO | -16 |
| .764 | C V O | -26 |
| .583 | O | -33 |
| .194 | R | -138 |
| .097 | RCNO, RCNO | -138 |

Agent($\alpha$=1/7, $\beta$=4/7, $\gamma$=2/7), "GW, *then* E now, *then* N"

| prob= | | des= |
|---|---|---|
| .325 | RCNO | 213 |
| .603 | N | 56 |
| .808 | C | 36 |
| .742 | O | 36 |
| .907 | R V C, R | 19 |
| .954 | R V N | 9.1 |
| 1.000 | T | 0 |
| .166 | RCNO | -16 |
| .351 | RN | -71 |
| .126 | RCNO | -73 |
| .397 | N | -84 |
| .258 | O | -105 |
| .099 | RCNO | -111 |
| .417 | C V O | -118 |
| .086 | RCNO, CN | -130 |
| .073 | RCNO | -149 |
| .192 | RC, C | -150 |
| .093 | R | -187 |
| .046 | RCNO, RCNO | -187 |
| .033 | RCNO, CO | -206 |

R, C, N, O Rankings

| Character α | β | γ | by Preference | by Probability |
|---|---|---|---|---|
| 0 | 1 | 0 | R, N, O, C | R, N, O, C |
| 1/2 | 0 | 1/2 | O, C, R, N | C, O, R, N |
| 0 | 1/2 | 1/2 | C, (R, N, O) | R, C, (N, O) |
| 1/3 | 2/3 | 0 | R, O, N, C | R, N, O, C |
| 1/3 | 1/3 | 1/3 | R, N, C, O | N, R, O, C |
| 1/7 | 4/7 | 2/7 | R, N, O, C | R, N, O, C |

α = 1 "No Nuclear"

β = 1 "Stop Global Warming"

γ = 1 "Max Energy Now"

*When confronted with new information, I reassess and modify my position.*

*What, sir, do you do when confronted with new information?*

-- John Maynard Keynes (1883-1946)

# Endnotes

[1] Richard C. Jeffrey, *The Logic Of Decision*, McGraw-Hill Book Company, NY, 1965; 2nd edition, University of Chicago Press, 1983, 1990, ISBN-0226395820

[2] Peter Schwartz and Doug Randall, "An Abrupt Climate Change Scenario And Its Implications For United States National Security," October 2003; (a report commissioned by the Pentagon, now public)

[3] "Researchers: Nuclear Materials 'Dangerously Vulnerable' To Theft," The Associated Press, 13 July 2006; http://www.truthout.org/docs_2006/071406C.shtml.

[4] *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

[5] "The Ocean Is Becoming Ever More Acidic," Stéphane Foucart, *Le Monde*, 17 June 2006; http://www.truthout.org/issues_06/062706EA.shtml

[6] "Human Development Report For 2005," *United Nations*, http://hdr.undp.org/reports/global/2005/pdf/HDR05_HDI.pdf

[7] "Electricity Consumption Per Capita," (UNDR 2005), *United Nations Development Programme (UNDP)*, http://hdr.undp.org/statistics/data/indicators.cfm?x=206&y=1&z=1

[8] "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

[9] "Asia Shows Solar Power Is Not Just For The Rich," Georgina Prodhan, *Reuters*, 27 June 2006; http://www.truthout.org/issues_06/062706EC.shtml

Contents

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