# *Some Thoughts on Energy and Sustainability*

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**TARDIS 2008**
**Leibnitz, Austria**

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# *Outline*

- **Energy and Sustainability**
- **Policy Options**
- **Summary and Reference**

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# Energy and Sustainability

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# Assumptions

**The rate of energy use (*E'*) is an increasing function of only two factors:**

**1. World gross domestic product (+WGDP)**

**2. The size of the human population (+H)**

***E'*** **is a decreasing function of only one factor:**

**1. Energy efficiency (-$\eta \equiv W/S$)**

$$E'(J/t) = E'(+WGDP, +H, -\eta)$$

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# Two More Assumptions

1. There is some average environmental impact ($I_E$) associated with the use of each Joule of energy.
2. The rate of environmental impact of using energy ($I_E'$) is the product of $I_E$ and $E'$.

$$I'_E\,(EI/t) = I_E(EI/J)\cdot E'(J/t)$$

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# More Considerations

1. **Since the Earth is finite, the rate at which it can dissipate the environmental impact associated with energy is also be finite.**
2. **There is a maximum value of $I'_{E\text{-}max}$ of impact dissipation rate for the Earth.**
3. **Sustainability is possible only if the rate of impact generation does not exceed the maximum dissipation rate, $I'_E \leq I'_{E\text{-}max}$.**
4. **Then, for sustainability $I'_E$ must then either be constant or decreasing with time or it will otherwise eventually exceed the maximum, $I'_{E\text{-}max}$.**
5. $dI'_E/dt \leq 0$

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# Sustainability Criteria

$$\frac{dI_E^{'}}{dt} = \left[ I_E \left| \frac{\partial E'}{\partial (WGDP)} \right| \left| \frac{d(WGDP)}{dt} \right| + I_E \left| \frac{\partial E'}{\partial H} \right| \left| \frac{dH}{dt} \right| - I_E \left| \frac{\partial E'}{\partial \eta} \right| \left| \frac{d\eta}{dt} \right| - E' \left| \frac{dI_E}{dt} \right| \right] \leq 0$$

# *Sustainability Criteria*

**$0 \geq dI'_E/dt$ = (Impact Increases with WGDP)**

**+ (Impact Increases with Human Population)**

**- (Impact Impact Decreases with Efficiency)**

**- (Impact Decreases with Technology)**

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# Policy Options

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# Practical Assumptions

1. **WGDP is likely to increase for the foreseeable future, d(WGDP)/dt > 0, with no hard upper bound.**
2. **Human population will likely grow for the foreseeable future, dH/dt > 0, with no hard upper bound.**
3. **Efficiency of energy use ($\eta$) has a hard upper bound set by thermodynamics and practical limits.**
4. **Environmental impact of energy use ($I_E$) has a hard, non-zero lower bound.**

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# Policy Options: Societal

$$I_E\left|\frac{\partial E'}{\partial(WGDP)}\right|\left|\frac{d(WGDP)}{dt}\right| + I_E\left|\frac{\partial E'}{\partial H}\right|\left|\frac{dH}{dt}\right| - I_E\left|\frac{\partial E'}{\partial \eta}\right|\left|\frac{d\eta}{dt}\right| - E'\left|\frac{dI_E}{dt}\right| \le 0$$

1. **Structural changes developed for shifting economy to non-energy intensive activities so rate of energy use does not rise or at least rises slowly as *WGDP* increases, i.e. $|\partial E'/\partial(WGDP)| \approx 0$.**
2. **Structural changes implemented for decreasing per capita energy use by shifting to low energy use society, so energy use either does not increase or increases slowly with human population, i.e. ($|\partial E'/\partial H| \approx 0$).**

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# Policy Options: Technological

$$I_E\left|\frac{\partial E'}{\partial(WGDP)}\right|\left|\frac{d(WGDP)}{dt}\right|+I_E\left|\frac{\partial E'}{\partial H}\right|\left|\frac{dH}{dt}\right|-I_E\left|\frac{\partial E'}{\partial \eta}\right|\left|\frac{d\eta}{dt}\right|-E'\left|\frac{dI_E}{dt}\right|\leq 0$$

1. **Increase the efficiency of energy use with time ($|d\eta/dt|>0$) up to the practical and thermodynamic limits by improving energy generation efficiency and reducing losses from energy use.**
2. **Increase the rate at which environmental impact associated with energy use is reduced ($|dI_E/dt|>0$) by development and deployment of environmentally benign technologies.**

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# *Summary & Reference*

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# Summary

1. Two categories of policy options: (1) societal – reducing energy use per unit of economic activity and reducing per capita energy use, and (2) technological – increasing efficiency of energy use and decreasing impact of energy use.
2. Societal policy options can be politically, legally, and culturally difficult to implement, but they have no “hard” upper (or lower) bounds.
3. Technological policy options can be easier to implement, but they do have hard upper bounds.

# *Reference*

**Cabezas, H., "On Energy and Sustainability," Guest Column, Clean Technologies and Environmental Policy, Clean Technologies and Environmental Policy, 8, 143-145 (2006).**