**21st Century Evolution of Anthropogenic Climate Change**

*Interactions between Social Systems and Natural Systems*

*An Integral Ecology Model (IEM) study*

*V. Ramanathan and Yangyang Xu We adopt the energy balance climate model of Ram & Xu (2010) and*

*Xu and Ram (2017) for evaluating the evolution of temperature changes as*

*a function of pollution emissions. The new features of the IEM are the following:*

1. *The emissions are dependent on responses of social systems to climate changes. These include: Societal Response; Policy Response in response to societal response; Development of pollution free technology; Adoption of new technologies, also, called as technology diffusion.*

*We first develop the pilot version of the model in which CO2 emission by fossil fuels is the only emission that is coupled to social systems. We prescribe the radiative forcing due to other pollutants; we also prescribe the CO2 emission from land use changes.*

1. *A) Tipping points triggered by ecosystem response to warming: Disappearance of Arctic Sea Ice; Amazon rain forests collapsing and emitting CO2; Methane emission from permafrost. In each case, the tipping point is the temperature change. B). Tipping points triggered by societal response to the warming.*
2. **Coupling CO2 emission to societal response**

Let E(t) be the total energy consumption per year. We can express E as follows:

(1)

Index i=1; denotes energy sources that emit CO2; and i=2 to n, denote non-CO2 sources of energy including renewables (wind, solar, geothermal, nuclear, hydro, etc). and the index j denotes the various sectors or sub-sources that emit CO2 within each category of the index i.

***The new IEM Approach:*** We obtain E(t), the total energy consumption, from data for the past years and from IAMs (such as IIASA) for the future.

The portioning between CO2 and non-CO2 sources of energy consumption is determined by coupling energy sources to societal response to climate change from CO2 and other greenhouse gases and aerosols.

We will obtain the Energy consumption due to CO2 emitting sources from Equation 2:

(2)

Where the left-hand side is the energy consumption due to CO2 emitting sources; and the right-hand side is the difference between total energy consumption and energy consumption due to renewable sources.

To give an example, for Zero carbon emission, the right hand side will be zero; i.e, all energy consumption is from renewables.

**I.1 CO2 emitting Energy Sources: i=1; k=2**

k = 1 denotes the fossil source; k=2 denotes non-fossil sources of energy consumption such as: non-renewable Biomass on time scale of a century (e.g. trees from Forests).

E12 (t)= Non-fossil fuel sources that emit CO2. We can set this term to zero; or better still, if there is data from 1900 onwards, we can prescribe it until 2015 and then keep it fixed at 2015 value for the future.

Let be the CO2 emission per year from fossil fuels; we can express it as:

(1.1)

where Fn denotes function of… The main contribution of this model is to make E11 and E12 dependent on societal response to climate change. E11 and E12 will be obtained from Eq 1.1 and using available data from energy consumption (i.e, E11 and E12) to CO2 emission, we will estimate the CO2 emission.

*From REN(2018) report, for the Year 2016: E11= 79.5%; E12= 7.8% (traditional non-renewable biomass); Rest from renewables.*

But if there is a more recognizable reference for this data, we can adopt that. The main important point is: we need to have hooks in the model for all these variables, so that we can get more sophisticated as we go along, without having to reprogram the model.

**I.2 Renewable Sources: i=2; k=1 to 4**

E21: Renewable using off-the-shelf technology: Photovoltaics; Wind; Biofuels. No development needed.

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Example: hydrogen from electrolysis, reusable batteries, safe nuclear, micro and nano-grids.

From REN-2018:

**I.2.1 Response of Renewable Sources to Climate Change**

We will develop the equation for the first renewable term: E21.

(2.1)

(2.2)

: societal response time

: policy response time

: technology development time

: technology diffusion time

The term within the square bracket, limits the growth. This limitation can come from limitations of land area, battery waste, etc.

Each of the response/Development/diffusion times are expressed as a function of warming as follows

(2.3)

(2.4)

; because tech is already developed

(2.5)

(2.6)

(2.7)

*Pl fix the eqn above. I did not want the denominator the way you had. So, I modified it but there is blank space still where there once was the denominator.*

(2.8)

are formulated the same way.

(2.9)

= 30 yrs

= 3

If

(3.0)

For the time being: Set  
 at 2015 values.

**Sources (geothermal; Hydro)**

Set E24 = Traditional Renewable and set it constant with time from 2015 onwards with value at 2015.

**E11: Fossil Fuel Sources**

Finally, we are ready to estimate the fossil fuel Energy consumption:

(4.0)

***Part II. Still to be Included: Eco System Tipping Points***

Atmospheric Carbon Extraction

Tipping Points

1: Social-System Tipping Points

Threshold; mass migration, govs close borders (?)

The poorest burn wood and coal for energy.

2: eco-system Tipping Points

A: Sea-Ice First:

Arctic at

Antarctic

B: Extra- tropical cloud system retreat

C: methane release from permafrost

D: Amazon rainforest die back (?)

First Steps of the Modeling for Annie:

**Trial 1: Call this case: T1.**

Let us start modeling the stuff below first:

Current renewable technology: solar+wind

(2.1)

Start the model at time to= 2016.

Follow all the equations in the text for this case.

Try two Cases:

1. = sum of the 4 time constants. Implicitly this case assumes that each response follows sequentially after the other: societal -> Policy -> Development -> Diffusion (i.e, adoption)
2. is the maximum of the four time constants; This case assumes that all four responses start simultaneously.

For T’, adopt the T’ for the CO2 only case. But don't use the CO2 emissions from the IEM; initially we will decouple the two models.

Plot T’ which is the input; and plot CO2 emissions.