Classwork-5: Scales of Population Dynamics and Energy Production

This project is designed to orient the student on the relationship of the different scales of population changes, renewable energy scales and capacity factors. The objective is to come up with some possible model for creating a world with a sustainable energy supply for 175 years with a high quality of life of at least HDI = 0.8.

The following data may be relevant for performing the quantitative analyses of questions 1-5.

- Assume current world population is 8 billion people.
- Assume current world total energy supply as 18 TWy.
- Assume per capita energy consumption per year for the entire world and the US as 75 GJ and 320 GJ respectively.
- Assume 12 m^2 of area is required to install a solar panel of 1 kW rated power capacity.
- Expected lifespan of single solar panel is 25 years.
- When calculating the materials required for solar panels assume densities of silicon (Si), silver (Ag), tin doped indium oxide (ITO) and plastic as 2.32, 10.5, 7.15, 0.9 t/m^3 respectively. Assume their respective volumes in a 1 kW rated panel to be 3.03×10^{-3}, 1×10^{-6}, 1.3×10^{-6} and 1×10^{-3} m^3 respectively, where t stands for a metric ton.
- Expected lifespan of single wind turbine is 30 years.
- Assume 5000 m^2 (0.5 hectare) of area is required to install a wind turbine of 1 MW rated power capacity.
- The quantity of stainless steel required for a wind turbine is 115 t/MW.
- The quantity of concrete required for a wind turbine is 590 t/MW.
- The quantity of fiberglass required for a wind turbine is 9,800 kg/MW.
- The quantity of cast iron required for a wind turbine is 23.9 t/MW.
- The quantity of copper required for a wind turbine is 2,500 kg/MW.
- 1 ha = 10,000 m^2.
- Assume total world consumption of crude oil is about 90 million barrels per day.
- Assume U.S consumption of oil is about 20 million barrels per day.
- Energy density of crude oil and ethanol are 31 MJ/L and 21 MJ/L respectively.
- Assume 158.6 bushels of corn is produced per acre.
- 2.77 gallons of ethanol are produced per bushel of corn.
- 1 oil barrel = 42 US gallons.
- 1 acre = 0.4047 ha.
- US total land area is 990 Mha.

- World total land area is 14.9 Gha.
- Total arable land in US is 175 Mha.
- Assume each nuclear reactor has a thermal efficiency of about 33%.
- 1 We is used to denote a Watt of electric power.
- To operate a 1 GWe power plant, one finds that ^{235}U isotopes have to be fissioned at a rate of roughly 10^{20} fissions/sec (about 0.05 grams/second).
- Assume 700 kg of high level wastes are produced per year by 1 GWe nuclear reactor.
- Given ^{235}U isotope makes up only 0.71% of natural uranium.
- Average ore grade of world remaining reserves of all isotopes of uranium combined is 1.22%.

Capacity factor**
indicates how much energy a source actually produces as a percentage of what it would generate if it were operating at its peak output 24 hours a day.

NUCLEAR	92%
COAL	80%
GEOTHERMAL	73%
SOLAR THERMAL	73%
NATURAL GAS	60%
HYDROELECTRIC	42%
WIND	21%
PHOTOVOLTAIC	15%

---

1. (a) How many solar panels with a peak capacity rating of 1 kW will be needed to provide primary energy for the world for a year?
   (b) What will be their total area. Use SI units only. What percentage of the US land area will this be? How much percentage of world land area would this be?
   (c) How much quantity of each of the different materials would be needed to fabricate these panels?
   (d) Once the entire installation is complete on an average how much power capacity of panels will have to be replaced per annum? Give your answer in TWy and also number of

panels per year. State what assumptions you have made and how you justify these assumptions.
(e) Answer all the above questions for WC values from parts (b) – (f) in question 5. Get these answers from team 5.
(f) How much percentage can solar energy contribute in a sustainable energy system. Think, analyze, discuss and then comment on all your answers.

2. (a) How many wind turbines with a rating of 1 MW be needed to provide primary energy for the world for a year?
(b) What will be their total area. Use SI units only. What percentage of the US and world land area will this be?
(c) How much quantity of each of the different materials would be needed to fabricate these turbines?
(d) Once the entire installation is complete on an average how much power capacity of turbines will have to be replaced per annum? Give your answer in TWy and also number of turbines per year. State your assumption in arriving at your answer.
(e) Answer all the above questions for WC values from parts (b) – (f) in question 5. Get these answers from team 5.
(f) How much percentage can wind energy contribute in a sustainable energy system. Think, analyze, discuss and then comment on all your answers.

3. Assume 90% of all crude oil consumption is needed for transportation. Suppose we decided to convert all cars and trucks in the US to pure bio-ethanol fuel derived ethanol.

(a) How much corn ethanol would be needed per year?
(b) How much farmland will be devoted to corn to create ethanol?
(c) What fraction of the US agricultural land will this be? What percentage of the US land area will this be?
(d) How much land will be left to grow other crops?
(e) Is this sustainable?
(f) What is the easiest solution to this problem? For your solution come with a similar set of questions a-e and their answers, to convince others that this is a sustainable solution.
(g) Answer the same questions but now for the world instead of the US.
(h) Answer all the above questions for WC values from parts (b) – (f) in question 5. Get these answers from team 5.
(i) How much percentage can corn ethanol energy contribute in a sustainable energy system. Think, analyze, discuss and then comment on all your answers.

4. Assume each nuclear reactor produce 1 GWe of power.

(a) How much ^{235}U is required for producing 1 GWy of electric energy?
(b) How many nuclear reactors are required to provide primary energy for the world for a year?
(c) How many nuclear reactors do we have in the world today and how many of these are in the US?
(d) By what multiple will we have to increase the number of nuclear reactors in the world if all the primary energy comes from nuclear sources alone?
(e) How much ^{235}U will be required if total primary supply of world energy came from nuclear source alone?
(f) How much natural uranium needs to be mined per year for this world primary energy supply of ^{235}U to be met?
(g) Given the ore grade level, of remaining uranium reserves, how many tons of soil will have to be dug up per year? Normalize this quantity in relationship to some other mining operation.
(h) How much waste will be generated in the scenario of part (e)?
(i) Answer all the above questions for WC values from parts (b) – (f) in question 5. Get these answers from team 5.
(j) How much percentage can corn ethanol energy contribute in a sustainable energy system. Think, analyze, discuss and then comment on all your answers.

5. In this question for each of the sub-parts (a) – (f) report the answer in units of TWy of consumption. These answers should be provided to Teams 1-4 along with the relevant assumptions when they need them. Assume the annual growth rate of the world population remains at 1% for 30 years. Assume world and also US annual growth rate of energy consumption per capita goes up by 1% per year for 30 years. World energy consumption (WC(y)) is to be computed under different assumptions. The year of computation is y.
   (a) Report WC(2024). This data has already been provided to you.
   (b) Calculate WC(2024) at US per capita rates of consumption from 2024.
   (c) Calculate WC(2054) with world per capita rates of consumption from 2024.
   (d) Calculate WC(2054) with world per capital rates of consumption from 2054.
   (e) Calculate WC(2054) at US per capita rates of consumption from 2024.
   (f) Calculate WC(2054) at US per capita rates of consumption in 2054..
   (g) Find the ratio of the answers in parts (b) – (f) to the answer in (a). By how much, if any, should world energy consumption be reduced or allowed to increase from 2024 levels for sustainable energy use. Think, analyze, discuss and then comment on all your answers.

Scales and Units

A1 Powers of ten

Some abbreviations for powers of ten in the International System of Units (SI) are listed below for convenience of the reader in Table A1.1.

Table A1

Exponent (n) of 10^n	Name of SI prefix	Symbol
24	yotta	Y
21	zeta	Z
18	exa	E
15	peta	P
12	tera	T
09	giga	G
06	mega	M
03	kilo	k
02	hecto	h
01	deka	da
-01	deci	d
-02	centi	c
-03	milli	m
-06	micro	μ
-09	nano	n
-12	pico	p
-15	femto	f
-18	atto	a
-21	zepto	z

-24	yocto	y

Caption Table A1. Table of prefixes for powers of 10 and their symbols in the SI system. For example one may use this table to express "10^{18} Joules" of energy as "1 exa-Joule" or just "1 EJ."

Units	J	kWh	kWy	cal	BTU	TOE	BOE	FGE
J	1							
kWh	3.6 M							
kWy	31.536 G							
cal	4.204							
BTU	1.055 k							
TOE	42.00 G							
BOE	5.7288 G							
FGE	1.055 M		33.45 μ					
MGE	35.275 M							
TCE	30.00 G							
SCE	27.00 G							

Caption Table 2.2. Table of conversions for different energy units. Except for values written from the definitions in the first column all other values are listed up to two digits after the decimal point. For example one cubic foot of natural gas of energy equivalent, FGE equals 33.45 micro kilowatt-year. It may be written as 1 FGE = 33.45 μkWy = 33.45 x 10^{-6} x 10^{3} Watt-year = 33.45 x 10^{-3} Wy = 33.45 mWy, which are all equivalent expressions.