RESOURCE SIMULATOR - a tool for scenario studies on limited resources

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Abstract

In this paper global resources have been gathered from different sources. From these resources scenarios have been made to get an overview of what resources will last at the present annual usage, as well as if we assume all individual would utilize the same amount or the difference between regions and populations. The most critical metal is according to this Zn, while also Cu, U, Co and Mn are relatively limited with reserves lasting in the range of 100 years. Some elements like P is not limited as such, but there is always a trade-off between total amount and at what concentration the extraction is made. For biomass and food we have enough resources if used efficiently. Wind, sun and hydropower are in reality unlimited resources for electricity production. We also have huge amounts of biomass. A question is what biomass should be used for. First it can be as a building material, then for chemical production and paper/packaging and last as energy source seems reasonable.

Keywords: *resources, simulation, predictions*

1 Introduction

There is a limited amount of resources available at Earth. Some of these are fossil, others renewable. Most resources utilized can be reused or recycled to a greater or smaller extent. The situation with respect to resources varies from country to country but can principally be grouped with respect to UN´s World Bank Statistics (2020) where data for each country (total 213) is collected but also grouped into “low income countries”, “middle income countries” and “high income countries”. We also look at regions of the world. Data from this is used in this paper for the resource simulation with respect to energy and environmental emissions. Other data from many different sources are complemented, and more detailed specification for specific factors described more in detail. The author has collected data during many years and published in books and papers. References are made to these as the data has been refined compared to original sources. These are then used for extrapolation to cover use today and possible scenarios for the future for countries in the three income groups. The simulations are made where the structure is set, but the use of resources varied.

2 Overview different resources

The most important input factors are Primary Energy sources, crops and raw materials (inorganics like metals). These are then utilized for heating, electricity production, transportation, food production and industrial use. In this section the resources are calculated and extrapolated into the UN grouping after income.

2.1 Energy

Primary energy is from Oil, Coal, Natural gas, Biomass, Waste, Sun, Wind, Hydropower and Geothermal energy. These resources are converted (Tomas-Aparicio et al., 2020) into useful forms like electricity, heat, cooling, transport work, industrial production, food production, building houses and other infrastructure. For these uses we also have input energy to manufacture wind power towers, PV-cell systems, thermal power plants, hydro power plants etc (Tomas-Aparicio et al., 2020). For transportation we can utilize fossil fuels and diesel or benzine vehicles, but also electric vehicles are coming fast (Irena, 2019; MacDicken et al., 2016). For the future we also see both more efficient engines as well as new energy conversion techniques like Fuel Cells utilizing Hydrogen as fuel. Biofuels can replace fossil fuels, but also replace use of oil or other fossil fuels for all kind of applications like production of plastics, chemicals, building materials etc. (Chaudhary et al., 2019; Larsson et al., 2018).

2.2 Other resources:

Recycling of materials is affecting the true input of both materials and energy. We have limited resources of metals and other inorganic materials as well as Phosphorous, while Nitrogen is a non-limited resource (Martinsen et al., 2020). On the other hand, conversion of Nitrous gas (N_2) to ammonia (NH_3) for e.g. use as fertilizer as well as “destruction” of ammonium compounds in waste water treatment plants consume huge amounts of electric energy.

In Table 1, we see the available resources as reserves, the annual use globally as well as the per capita use of important materials. We also see how much energy is used for production per kg related to virgin material or recycled material at typical recovery rates today in OECD countries.

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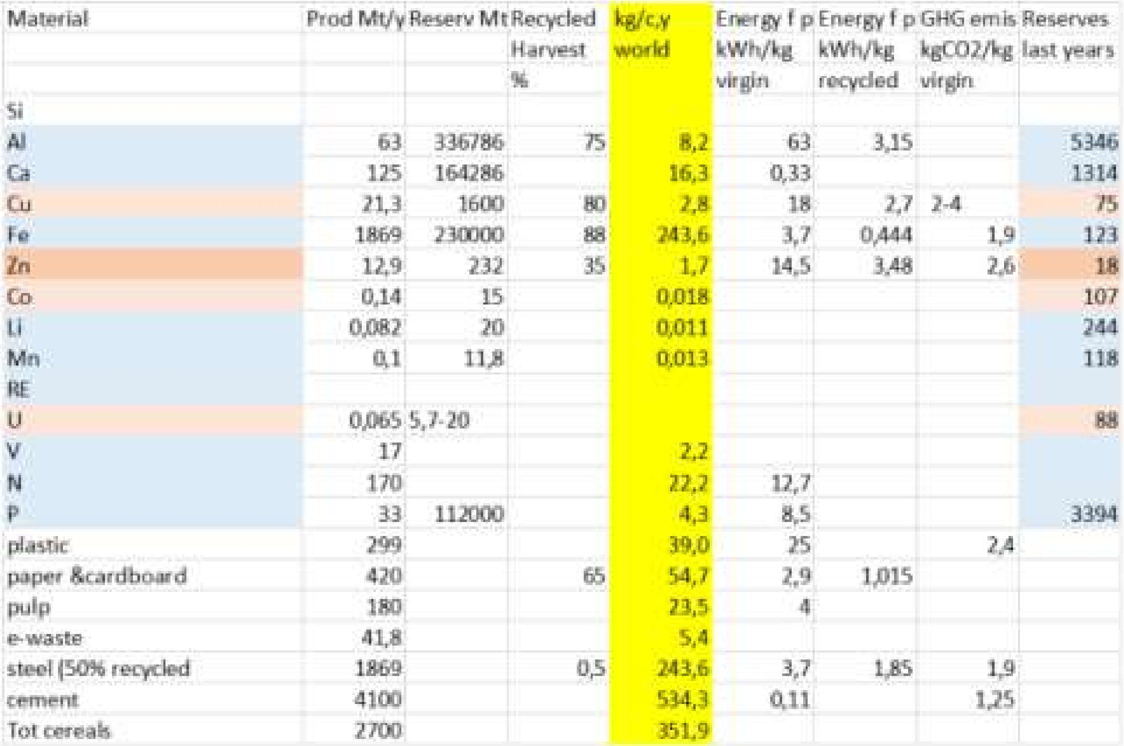
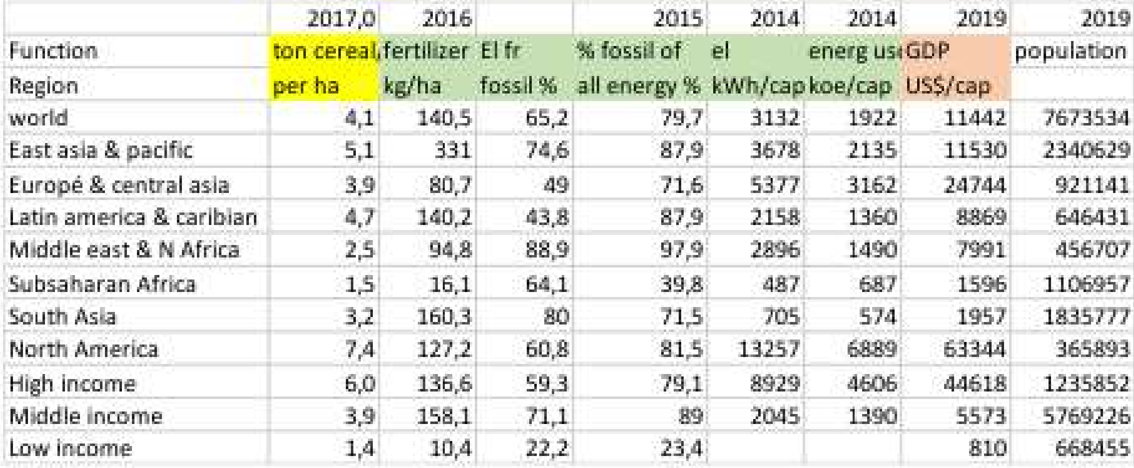
Table 1. Important resources – annual extraction, reserves, and energy for processing.



Material	Prod Mt/y	Reserv Mt	Recycled Harvest %	kg/c,y world	Energy f p kWh/kg virgin	Energy f p kWh/kg recycled	GHG emis kgCO2/kg virgin	Reserves last years
Si								
Al	63	336786	75	8,2	63	3,15		5346
Ca	125	164286		16,3	0,33			1314
Cu	21,3	1600	80	2,8	18	2,7	2-4	75
Fe	1869	230000	88	243,6	3,7	0,444	1,9	123
Zn	12,9	232	35	1,7	14,5	3,48	2,6	18
Co	0,14	15		0,018				107
Li	0,082	20		0,011				244
Mn	0,1	11,8		0,013				118
RE								
U	0,065	5,7-20						88
V	17			2,2				
N	170			22,2	12,7			
P	33	112000		4,3	8,5			3394
plastic	299			39,0	25		2,4	
paper &cardboard	420		65	54,7	2,9	1,015		
pulp	180			23,5	4			
e-waste	41,8			5,4				
steel (50% recycled	1869		0,5	243,6	3,7	1,85	1,9	
cement	4100			534,3	0,11		1,25	
Tot cereals	2700			351,9				

Table 2. Annual crop production; use of fertilizers and energy; GDP per capita and population in different regions and income groups.



	2017,0	2016		2015	2014	2014	2019	2019
Function	ton cereal,	fertilizer	El fr	% fossil of	el	energ us	GDP	population
Region	per ha	kg/ha	fossil %	all energy %	kWh/cap	koe/cap	US$/cap	
world	4,1	140,5	65,2	79,7	3132	1922	11442	7673534
East asia & pacific	5,1	331	74,6	87,9	3678	2135	11530	2340629
Europé & central asia	3,9	80,7	49	71,6	5377	3162	24744	921141
Latin america & caribian	4,7	140,2	43,8	87,9	2158	1360	8869	646431
Middle east & N Africa	2,5	94,8	88,9	97,9	2896	1490	7991	456707
Subsaharan Africa	1,5	16,1	64,1	39,8	487	687	1596	1106957
South Asia	3,2	160,3	80	71,5	705	574	1957	1835777
North America	7,4	127,2	60,8	81,5	13257	6889	63344	365893
High income	6,0	136,6	59,3	79,1	8929	4606	44618	1235852
Middle income	3,9	158,1	71,1	89	2045	1390	5573	5769226
Low income	1,4	10,4	22,2	23,4			810	668455

The most critical metal is according to this Zn, while also Cu, U, Co and Mn are relatively limited with reserves lasting in the range of 100 years at present consumption level. Some elements like P are not limited as such, but there is always a trade-off between total amount and what concentrations there are where the extraction is made. With more efficient separation methods, the available amounts are increasing. Still, we should know the estimates of available resources of different elements are built on a limited number of measurements, especially for the rarer elements.

2.3 Emissions

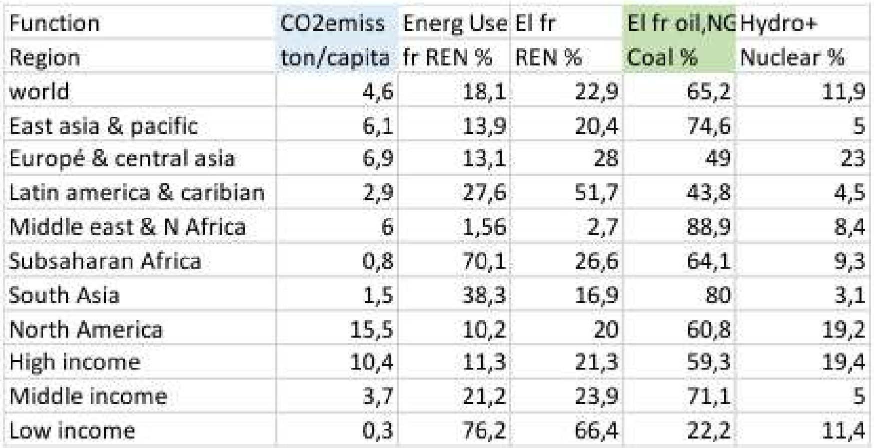
Conversion of fossil fuels release CO_2 that has been bound in earth for millions of years. When released we get a greenhouse effect. For biomass we have a release of CO_2 as well, but this CO_2 is bound back into new crops through photo synthesis. It is then interesting to evaluate how much biomass we have as a "storage" globally, and what happens if we take out biomass or just let it degrade in nature. There are voices saying that we should let the forests stand to store CO_2 long term.

In a few decades perspective this is correct, but long term the trees stop growing and will not absorb more

CO_2. When the trees finally dies, they are degraded by microorganisms and fungi while releasing both CO_2 and CH_4. CH_4 is approximately 25 times stronger as greenhouse gas than CO_2. Also, N_2O may be released simultaneously, especially if there is a deficiency of oxygen. If we take out a certain amount of wood and let the forest reproduce itself continuously, we will get material for use in many ways. In Table 2, we can see that cereal productivity varies a lot between regions and this correlates to climate differences and use of fertilizers generally. GDP/capita is dramatically different, but the differences are reduced by time. In Table 3, we see that renewable energy is dominating in low-income countries and especially in Africa south of Sahara. We can also see that electricity from fossil fuels is highest in middle income countries. High income countries have reduced the fossil part significantly, while low-income countries use a lot of especially hydro power, aside of biomass.

From this we can see that there is a huge potential to increase productivity in low income countries but also that CO_2 emissions are many times higher in high income countries than low income countries. The challenge will be to reduce CO_2 emissions in high income countries and increase yields in low-income countries without increasing CO_2 emissions.

Table 3. Distribution of REN (PV and wind), Hydro + Nuclear power respectively fossil fuels and CO_2 emission per capita in different regions and income groups.



Function	CO2emiss	Energ Use	El fr	El fr oil,NG	Hydro+
Region	ton/capita	fr REN %	REN %	Coal %	Nuclear %
world	4,6	18,1	22,9	65,2	11,9
East asia & pacific	6,1	13,9	20,4	74,6	5
Europé & central asia	6,9	13,1	28	49	23
Latin america & caribian	2,9	27,6	51,7	43,8	4,5
Middle east & N Africa	6	1,56	2,7	88,9	8,4
Subsaharan Africa	0,8	70,1	26,6	64,1	9,3
South Asia	1,5	38,3	16,9	80	3,1
North America	15,5	10,2	20	60,8	19,2
High income	10,4	11,3	21,3	59,3	19,4
Middle income	3,7	21,2	23,9	71,1	5
Low income	0,3	76,2	66,4	22,2	11,4

3 Scenarios for the future development – Results and Discussions

What would happen if we replace all fossil fuels with biomass? Will there be enough biomass to cover all demands?

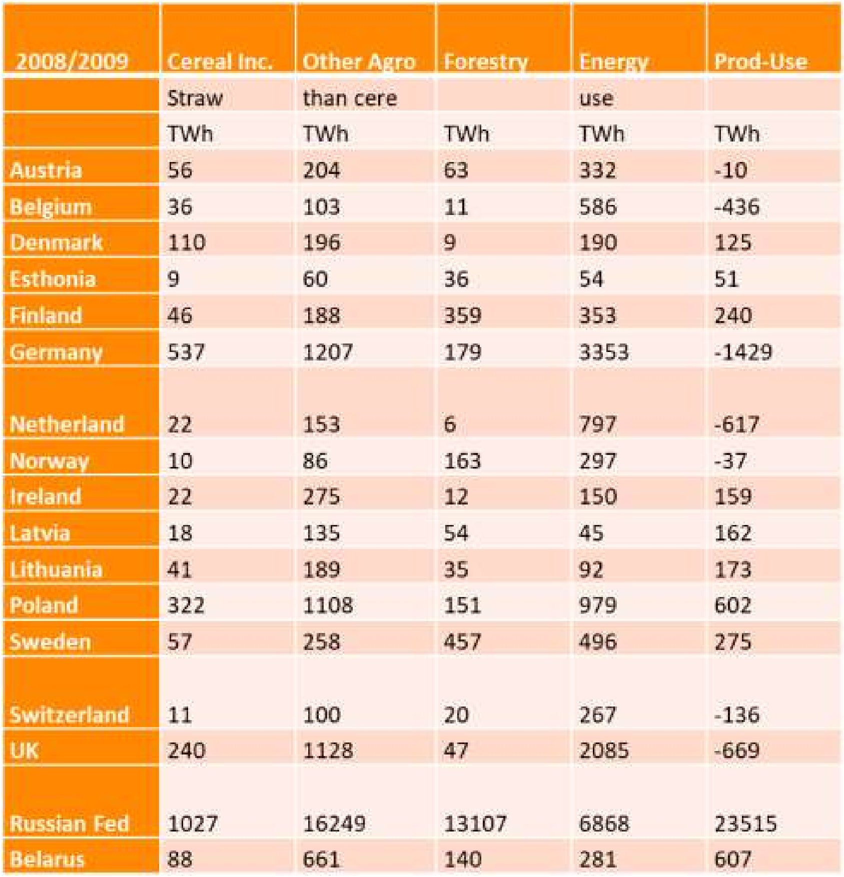
In Worldbank database we can find the area in different countries and regions given in km2 or ha. This is for Agricultural land, arable land and forests, as well as more detailed data on how many ha are used for production of different cereals, which is the major food for humans. We can see a very strong development in cereal production last 60 years. This is depending on increased use of fertilizers, irrigation, and better crop species. In Table 4, we can see such balances for Europe where we have assumed 5 ton DS cereal grain/ha,y, but also assume some additional (2.5-) 5 ton DS/y as straw and root system. 5.4 MWh/ton DS for the heating value has been used.

The production can be significantly higher, but also in more arid areas lower. For forests in northern boreal areas the production is in the range 2 ton DS/ha,y as “productive biomass”, with an additional 1 ton DS/ha,y at least as roots, bark and leaves. In sub-tropical and tropical areas these values are normally higher, and for some species significantly higher like up to 10 ton DS/ha,y for Salix, Eucalyptus, Acacia and similar. Probably the production in Russia is significantly lower than the average due to colder climate.

The annual forest growth is calculated to be 121 miljoner m3sk/y if only logs are included. If we include also roots and branches this corresponds to 93-million-ton DS. 84 million m3 are taken out by harvest and another 12 degraded in the forest. This means that the annual storage volume is increasing with 25 million m3/y corresponding to 25-million-ton CO_2. This can be compared to the total emissions of CO_2 in Sweden of 53-million-ton CO_2 according to Skogforsk (2019). We have a similar situation in most boreal forests, where the biomass storage is increasing.

For subtropic and tropical forests though the outtake of biomass is often larger than the growth rate. The IPCC report (2019) presents the global balance for CO_2 for year 2005: Emission to air due to change of land use is estimated to be 1.6 Gton C/y, while increase of biomass in forests 2.6 Gton C/y. This can be compared to annual emissions through combustion of fossil fuels, 6.4 Gton C/y. From 2005 to 2014, the sum of the national GHG inventories net emission is estimated to be 0.1 ± 1.0 GtCO2/y, while the mean of two global bookkeeping models is 5.2 ± 2.6 $GtCO_2$/y (likely range). Global net removals is estimated to be 11.2 ± 2.6 $GtCO_2$/y (likely range) during 2007– 2016. The sum of the net removals due to this response and the AFOLU net emissions gives a total net land-atmosphere flux that removed 6.0 ± 3.7 $GtCO_2$/y during 2007–2016 (likely range) (IPCC, 2019).

Table 4. Balance between energy use and crop production in Northern Europe as TWh/year.



2008/2009	Cereal Inc.	Other Agro	Forestry	Energy	Prod-Use
	Straw	than cere		use	
	TWh	TWh	TWh	TWh	TWh
Austria	56	204	63	332	-10
Belgium	36	103	11	586	-436
Denmark	110	196	9	190	125
Esthonia	9	60	36	54	51
Finland	46	188	359	353	240
Germany	537	1207	179	3353	-1429
Netherland	22	153	6	797	-617
Norway	10	86	163	297	-37
Ireland	22	275	12	150	159
Latvia	18	135	54	45	162
Lithuania	41	189	35	92	173
Poland	322	1108	151	979	602
Sweden	57	258	457	496	275
Switzerland	11	100	20	267	-136
UK	240	1128	47	2085	-669
Russian Fed	1027	16249	13107	6868	23515
Belarus	88	661	140	281	607

If we look at a scenario where productivity in forests would be globally as in Sweden we can see that today harvested forests globally is 2997 Mt/y (see Table 5) with an annual growth of 0.8 m3/ha,y and a harvested production of 260 kg Wood/capita,y. In Sweden the annual growth is 1300 kg/capita,y and 4 m3/ha,y, that is five times higher. With the same growth rate at average globally it would mean 14 985 Mt/y. With a heating value of 5.4 MWh per tDS wood this corresponds to 16 183 TWh with today´s harvests but 80 919 TWh/y if we could reach Sweden´s average. The reported value today in World bank data base is 21 800 TWh/y for biomass plus waste. If we summarize the probable production (annual growth) from all crops today we come to approximately 250 000 TWh/y assuming 5.4 MWh/ton DS.

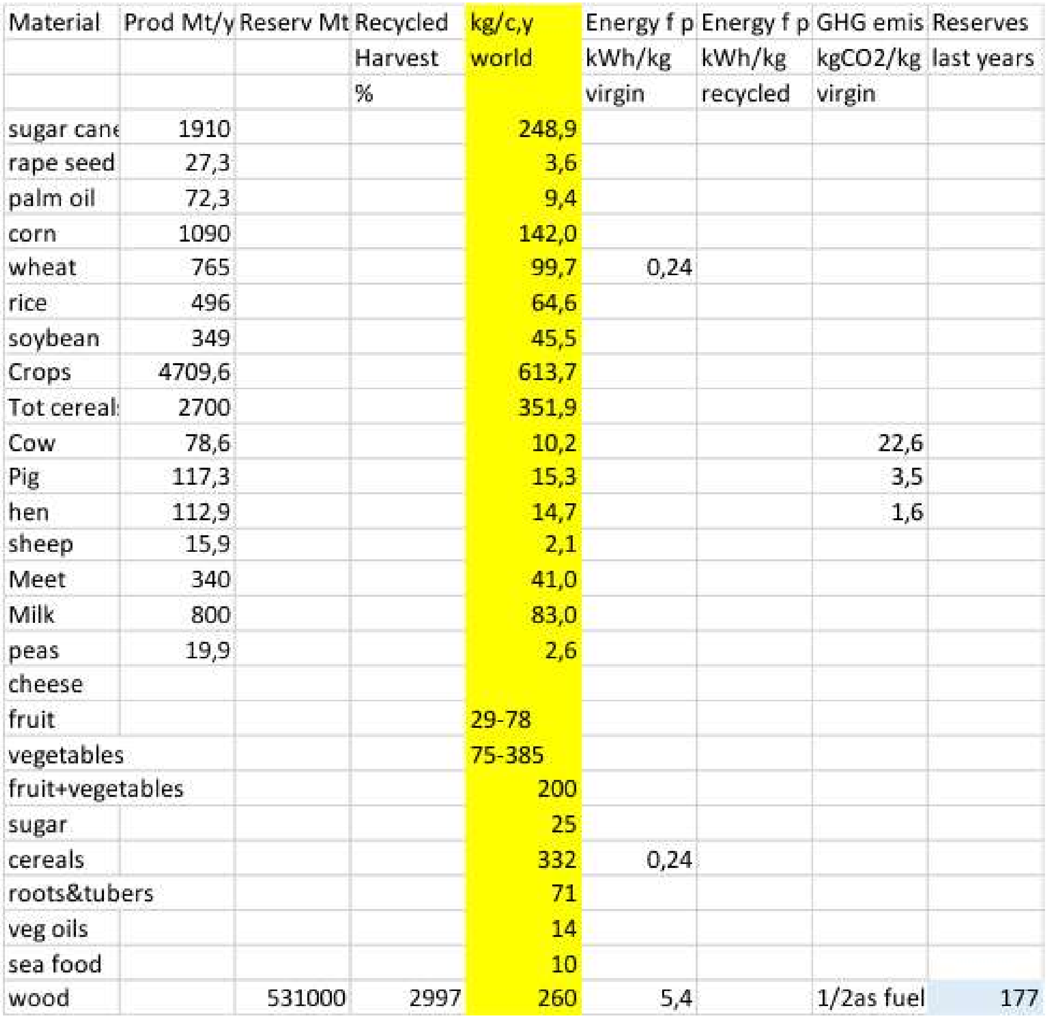
This is more than the approximately 160 000 TWh energy we use annually, from which approximately 80-85 % is coming from fossil fuels, and only 10% from biomass in official statistics.

As can be seen the potential for increasing biomass production is significant if we would optimize with respect to optimal amount of water, fertilizer and light, as well as temperature and suitable species. This gives a huge potential for production also indoor in buildings like in the cellars and at roof tops. This also would be needed as a lot of productive land has been destroyed by buildings and road systems.

How will different technologies like wind and PV affect the system?

Sun is the major energy resource. It is driving weather systems like wind and hydro power, as well as PV systems. The only other source we have is nuclear reactions directly in the ground or after refinement in nuclear reactors. Neither sun nor nuclear are renewables, but both can be considered as being it as the time perspective is very long. The fossil fuels were produced from biomass more than 100 million years ago and due to this is affecting the climate due to greenhouse effects when burned, and thus should be avoided. The biomass is emitting CO_2 but is incorporated back into crops continuously, and thus do not give increased temperature long term (range 100 years), at a balance point. If we look at the energy resources we use today it looks like in Table 6.

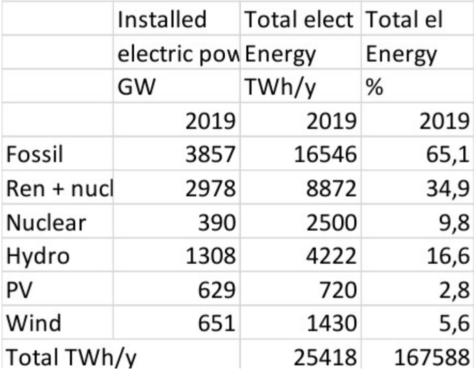
Table 5. Annual global production, harvest and stock of crops totally (Mton/y) and as per capita and year.



Material	Prod Mt/y	Reserv Mt	Recycled Harvest %	kg/c,y world	Energy f p kWh/kg virgin	Energy f p kWh/kg recycled	GHG emis kgCO2/kg virgin	Reserves last years
sugar cane	1910			248,9				
rape seed	27,3			3,6				
palm oil	72,3			9,4				
corn	1090			142,0				
wheat	765			99,7	0,24			
rice	496			64,6				
soybean	349			45,5				
Crops	4709,6			613,7				
Tot cereal	2700			351,9				
Cow	78,6			10,2			22,6	
Pig	117,3			15,3			3,5	
hen	112,9			14,7			1,6	
sheep	15,9			2,1				
Meet	340			41,0				
Milk	800			83,0				
peas	19,9			2,6				
cheese								
fruit				29-78				
vegetables				75-385				
fruit+vegetables				200				
sugar				25				
cereals				332	0,24			
roots&tubers				71				
veg oils				14				
sea food				10				
wood		531000	2997	260	5,4		1/2as fuel	177

We can see that 82-83% of the primary energy (totally 167 588 TWh/y) is with fossil fuels. For electricity production (totally 25 418 TWh/y) the figure is 65 % from fossil fuels. What is remarkable is that wind power and solar power is increasing so dramatically fast. Today (2021) the installed capacity for solar power (629 GW) and wind power (651 GW) is together in the same range as hydro power (1308 GW). If we add all non-fossil power production capacities, we get 2978 GW while for fossil fuels we have approximately 3900 GW. This means 44 % installed capacity from non-fossil technologies. It is true that the capacity factor is lower for the non-fossil techniques, but this is increasing a lot due to much higher wind power towers taking wind from where it is stronger. Also, PV cells becomes more efficient, almost twice as high per m2 as 15 years ago. With high power transmission lines, it should be possible to balance demand to wind and sunshine over larger regions in the future. The capacity factor is in the same range for offshore wind power at the North Sea as for coal fueled power plants, around 50 %! Concerning biomass only 10% of the total primary energy demand is used globally, although the production could principally cover all demands. There will be significant increase in electricity demand when going from internal combustion engines to electric motors in vehicles, but also significantly less primary energy use as electric engines are so efficient. If electricity is stored in batteries or as fuel (H_2) and used in fuel cells both alternatives will be complementary.

Table 6. Global power generation and installed capacity by different methods.



	Installed electric pow GW	Total elect Energy TWh/y	Total el Energy %
	2019	2019	2019
Fossil	3857	16546	65,1
Ren + nucl	2978	8872	34,9
Nuclear	390	2500	9,8
Hydro	1308	4222	16,6
PV	629	720	2,8
Wind	651	1430	5,6
Total TWh/y		25418	167588

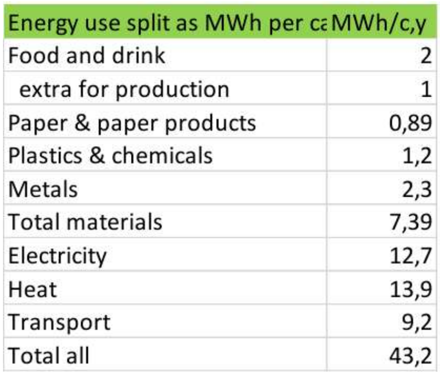
3.1 Use of resources

In Table 7, we see the distribution of different resources for Sweden per capita as MWh/y,c.

All materials together amount to approximately 7 MWh out of 43, which means 16%. The electricity is also including power for industry and will increase further as electric power will replace fossil fuels, while the heat will go down due to more heat efficient buildings. As we get more electric vehicles the energy for transportation will also go down.

What are limiting resources and how could these be recycled long term – Phosphorous, Nitrogen, rare metals, other materials?

Table 7. Energy use per capita and year for the average Swede, MWh/capita,year.



Energy use split as MWh per c	MWh/c,y
Food and drink	2
extra for production	1
Paper & paper products	0,89
Plastics & chemicals	1,2
Metals	2,3
Total materials	7,39
Electricity	12,7
Heat	13,9
Transport	9,2
Total all	43,2

Phosphorous (P) and Nitrogen (N) are key elements in all biological bodies and crops, aside of primarily C, H and O. This means that all crops we grow to produce food demand a certain amount of P and N per kg product. Today we recirculate manure from animals, but also a lot of additional P is coming from mineral resources from e.g. Spanish Sahara/Morocco. Available resources have been gatherd in (Dahlquist, 2013; Dahlquist and Hellstrand, 2017; Sigson and Dahlquist 2017). There are also large amounts available in other minerals like Thomas Phosphate in iron ores in e.g. Northern Sweden. Still, the available amount is a limiting factor for crop production, and we should recycle as much as possible. This demands recovery from wastewater treatment plants, organic residues in sludges etc. It would also be interesting to recover Nitrogen in wastewater treatment plants (Caballero et al., 2012). The energy to produce ammonia is approximately 13 kWh/kg, while the electricity needed for degrading NH4 to N2 in activated sludge processes is also approximately 13 kWh/kg. If we could reuse N instead of destroying NH_4/NO_3 and recycle back sludge to farmland we thus could save 2*13= 26 kWh/kg principally!! Still, today there are no efficient processes for this, but the Anamox process at least reduces the energy demand for the destruction to half. But by using selected species of microorganisms, it should be possible, to reach at least much further than today. Here advanced control and learning systems will be very interesting in the future (Dahlquist et al., 2021).

Other limited elements are e.g. rare earth metals and similar. A problem here is that these are not equally distributed in the ground and a few countries control production which may cause political problems in the future. In Table 1, we see how long known reserves of different elements would last at today´s extraction rates. For Cobolt, Niob and Zink we have quite limited resources, but also for Iron because it is used in such large volumes. This concerning mines with relatively high concentration of iron.

3.2 Industrial use and possibilities

We are using 39 kg/capita,y of plastics at average globally. Will there be enough wood to replace fossil fuels for plastic and chemical products production?

We have 260 kg Wood/capita,y available, so principally there should be no problem. The Swedish consumption of plastics and chemicals is 1.2 MWh/capita,y which corresponds to 48 kg plastic and chemicals. To produce this from wood we would need some 75-100 kg wood/capita,y.

Can we replace coal with hydrogen in steel production?

The global steel production today is 1869 Mton/y with use of 3,7 kWh/kg for virgin iron production and 0,44 kWh/kg if recycled assuming recycling rate of 88%. It would be 1,85 kWh/kg if the recycling rate was 50% instead. This means 1869 Mt/y *3.7 MWh/ton iron or 6915 TWh/y. With 0.44 MWh/t it would be 822 TWh/y. Today almost only fossil fuels, especially coal, are used giving huge fossil CO_2 emissions. Approximately 1.9 t CO_2 is emitted per ton steel at average. The total emission then is 1869 Mt/y*1.9 tCO_2/t = 3 551 Mt CO_2/y. The global anthropogeny CO_2 emission is estimated to be 36 000 Mt/y and thus approximately 10% is coming from steel production if all is from virgin iron. If we instead could utilize

Hydrogen for the reduction, we principally need 1 kg H2 to replace 3 kg C (2 H2 +O2 – 2H2O compared to 1 C+ O_2 – 1 CO_2, but 2 H_2 has molar weight 4 while 1 C has molar weight 12. Ratio 12/4=3). 1 kg H_2 demand 58 kWh electricity for the electrolysis today. 3 kg C as coal contain 3*7 kWh/kg = 21 kWh. This means 58/21 = 2.76 times more energy. For virgin iron it would mean 19086 TWh/y but 2270 TWh/y if we use 88% recycled iron. The total annual wind power production is 1430 TWh and thus the energy demand would be 13 times the total annual production of wind assuming only virgin iron, but with 88% recycled iron 1.6 times more than total production. Still, this shows that replacing fossil fuels in steel reduction is less rewarding than replacing fossil fuels in vehicles.

Can use biomass instead, or as a complement for reduction of iron oxide?

For reduction of iron ore (oxides) an alternative is to gasify biomass. Also raw material for bio-diesel and chemicals could be produced from pyrolysis of biomass combined with gasification in CHP plants. Here we then can utilize the reaction heat for district heating/cooling and produce electricity as a balancing production when there is little wind and sun. We probably need at least twice as much biomass for the production, although the rest also will be utilized. This means some 15 500 TWh/y. If we look at the potential biomass production with same productivity as Swedish forests, it means 80900 TWh/y. This means that there should be a good potential to do this also in reality.

What would the impact be on material use and energy demand for transportation if we go for electric vehicles with batteries compared to replacing fossil fuels with biofuels/renewables (including Hydrogen) ?

For transport sector we today have almost all fuels being fossil, 30 200 TWh/y globally. The electric engines are much more efficient so to replace the fossil fuels we demand approximately 25-30% of that energy only. This means that we need 30 200 TWh/y *0,25 = 7 550 TWh electricity to replace the fossil fuels. Here the replacement of fossil fuels with electricity makes much sense! For use of Hydrogen we will need less kWh/km if we use fuel cells with high efficiency. We can expect up to 80% efficiency in the future, but significantly lower today. Even the compression of the hydrogen consumes some 15-20 % of the heating value. So here batteries look better from a system perspective if all materials are recycled at end of life. (Ottorino editor, 2017).

How much resources are we utilizing per capita and what would happen if everyone would have access to same amount of resources as the one spending most, average or least?

Some metals are very common in the earth crust, like iron and aluminum. These are very important for production of machinery, vehicles, and buildings. For others like Cobolt, Niob and Litium we have limited resources. These are important for production of high efficiency motors in wind power plants and for production of Litium ion batteries. When we want to scale up the production of new technologies, we will see either increased price due to limited supply or a transfer to use of other materials or combination of materials. Probably we will se a combination of these.

What is the impact if everything is produced locally compared to a free market where a lot of goods is transported longer or shorter distances?

If we produce most products locally, we will reduce the amount of fossil fuels used for transportation. At the same time the competition will be lowered and thus the prizes higher. This can be seen clearly in Sweden. Before joining EU Sweden was producing most food like meet in Sweden. After joining EU the price on meat was lowered to roughly and thus the import became important and is now approximately 50% of what is consumed (SCB, 2020). For some product like fish fingers long chains are seen, where fish can be taken up in the North Sea. Filets are made in France. These are sent to China where they are cut and covered by bread crisp. After this back again to Europe for packaging and distribution to end customers. It is difficult to claim that one alternative is better than the other generally, but we should act in a rational way. Then different regulations on energy and resources might be a way to direct how we should act.

How would food production look like if we produce much more in our cellars or at the roof in aquatic systems without soil compared to only at farmland? Can insect larvae produced from waste be a new food?

There are several projects going on in many parts of the world to produce vegetables and spices in buildings. One example is Swegreen, who produce vegetables for shops in Stockholm in the cellar of a sky scraper and recently inside a shop in Gothenburg (Swegreen, 2020). Other examples are roof top plantations in New York, Gothenburg, Stockholm and other cities. In Eskilstuna food waste is converted into larvae of Black Soldier Flies. A yield of 30-36 % from waste to larvae has been achieved with high content of protein (40%) and fat (30%) (Lalander et al., 2020). The plan is to use as fish fodder at first, but later also for other animals and possibly also for humans.

To produce meat, consume a lot of fodder for the animals. The Lancet commission (Willet et al., 2019) has concluded that we should reduce the intake of especially red meat significantly, both for health reasons, and to enhance the efficiency from crop to humane use. One kg of beef may consume 19.8 kg of fodder (Lesschen et al., 2011). At the same time cows emit a lot methane, some 135 kg CH_4/cow,y. There are approximately 1000 million cows (Statista, 2020), which means 135 million tons CH_4/y. The global impact then would be 3 375 million CO_2 eq. By absorbing most of this, 85 %, in active coal filters could then reduce emissions by 2 870 million ton CO_2eq/y. At the same time the heating value of the recovered CH_4 would be approximately 1150 TWh/y, all non-fossil biogas!

What is the potential to make more efficient buildings and more efficient industrial processes.

Sun has been utilized to heat buildings since long, but due to poor design there is a much wider potential. By having large windows heating can be achieved during spring and autumn but shaded off during summer to avoid overheating. In the EU project PLEEC, planning of energy efficient cities, good examples of both technologies, behavior changes and also organization of work in cities was reviewed go find best possible methodology for different type of cities (Dahlquist et al, 2015; Kullman et al, 2016). Concerning more efficient industries EU SPIRE program has had several projects on this, where Fudipo can be mentioned. The potential savings for EU process industries is in the range of 300- 500 TWh/y (Dahlquist et al., 2021).

How can we make energy balances where no fossil fuel is used on different levels from regions to countries and globally?

In several articles we have made energy balances for regions, countries and globally. They are presented in e.g. (Dahlquist et al., 2012). The general conclusion is that there are enough resources, but we need to use these in a fair and knowledgeable way. This means use methods guaranteeing biodiversity and a fair distribution of the resources to all humans, but also give animals and crops reasonable conditions for the future.

4 Results an discussion

How can the simulator be used?

In Tables 1-7, we find a lot of basic information: Table 1 shows annual consumption vs total resources for important materials, and in Table 5 consumption of food species. In Table 2, we have key data on population and use per capita for energy use, income and crop production per capita. Table 3 and 4 are energy conversion related while Table 7 shows distribution between different human needs in a high-income country. With the simulator you principally multiply per capita use (X_c) with number of people (Pi) in a region or income group (i). Consumption per capita (Ci) is assumed to be proportional to income in an income group to high income group (Ch). Total consumption for a group (X_t) then is calculated as:

$$Xt = Xc * Pi * Ci/Ch \qquad (1)$$

With Y% recycling of materials we can get a net consumption of virgin materials and resources (Xt,r) as:

$$Xt,r= Xt * (1-Y) \qquad (2)$$

The global consumption (Xg) then will be for all regions or all income groups (i):

$$Xg = \sum n\, Xt, r, ii \qquad (3)$$

What could be mechanisms to drive a society in one direction or the other?

Different economic incentives and regulation, CO_2 tax and similar is one way. Information campaigns and showing good examples another. How different mechanisms have been successful or not can be discussed from a historical perspective. Freons and Montreal protocol was successful, while Kyoto protocol not so successful. In the first case there was principally only one supplier of Freons, Dupont. Then it was easy to push this company. The Kyoto protocol should reduce the use of fossil fuels, where countries like China, the US, Poland and Germany all have strong interests in domestic resources. Then national interests stand against global ones. Sulphur tax versus emission rights on a regional level have both been successful, but in different time scales. Carbon tax in Sweden has been very successful to move over from oil to biomass and a governmental drive for nuclear power replaced half of the major primary energy source oil from 1970 to 1990. This is showing that it is possible to make changes, but it is tough to get everyone “on-board”.

Concerning information campaigns and similar it has not been so successful to really achieve long-lasting changes, although it paves the road for the other regulatory mechanisms, which is important! If good examples can be demonstrated and regulations give the incentive, we can get fast changes like the introduction of wind power and solar power on a large scale last 20 years!

5 Conclusions

There are huge possibilities to make the globe sustainable. In this paper it is shown how different actions could be used. There are mostly several different technical solutions giving the same result and thus it is best if we can develop several different technologies in parallel and have mechanisms driving towards the primary goal to reduce global warming more general. International regulations and agreements are important. Information and mass-media has an impact, but mostly to give the politicians incentives to "make the right decisions". The simulations in this paper are not strict mathematical but more discussions around different scenarios. It should be noticed that this is an alternative type of simulation that could be utilized more.

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