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SOLUTIONS

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Solution 1. Where is carbon

Is it the air? Although carbon dioxide plays a crucial role in regulating climate, it is actually only a tiny proportion of the atmosphere (which consists primarily of oxygen and nitrogen). However, the atmosphere is huge (it weighs around 5000000 Gt*), so even a tiny part of it can still store a vast amount of carbon. Every year, the oceans and the living things on land add 770 Gt of CO_2 to the atmosphere and remove 790 Gt. This is known as the fast carbon cycle. Since the 1850s, humans have been disturbing the balance. Currently, we emit 40Gt of CO_2 per year, so the extra 20 Gt of CO_2 per year stays in the atmosphere. It has been building up, trapping heat and causing climate change. There is a lot of carbon in the atmosphere, but that's not where most of it is found ….

Water: The oceans and surface waters (rivers and lakes) have 50 times as much CO_2 as the atmosphere. You can find carbon dioxide dissolved in water, and like plants on land, aquatic plants take up CO_2 when they photosynthesise, then release CO_2 when they respire or decompose. Since humans started altering the balance of the carbon cycle, the oceans have been acting as a carbon sink, absorbing the extra carbon we add through burning fossil fuels or clearing forests. This has led to ocean acidification and is harming marine life.

Plants, animals, and other organisms: All known living things are carbon-based. You yourself are 20% carbon, by weight. Overall, the biosphere stores about 550 Gt of carbon.

Sediments, Soil, and Fossil Fuels: As living things die, their carbon is stored in soils (that store about 2300 Gt of carbon). It took millions of years for Earth to transform formerly living things into carbonate rocks and fossil fuels. Now, by burning them, we are releasing ancient carbon (and energy), injecting it into the fast carbon cycle and hence destabilising the climate.

Earth's interior: In contrast to living things, our planet as a whole is only 0.025% carbon. But the Earth is a large rock so this all adds up to about 100 million Gt of carbon. *Most of the carbon in our climate system is actually in the Earth's interior.*

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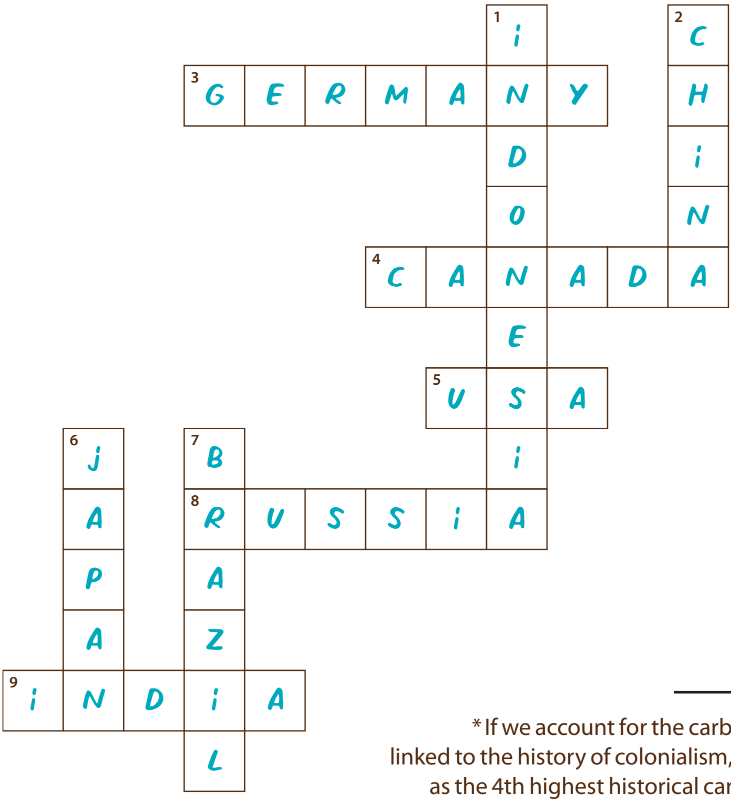
* 1 Gt = 1000 000 000 000 kilograms

Solution 2. Top 10 historical emitters

"Who has contributed the most?" is not a straightforward question. For example, should we only count emissions that have occurred within a country's borders, or should we also include emissions associated with the goods and services they import? And what about population sizes? Per-person production emissions are currently highest in Qatar (36 tonnes per year) and lowest in the Democratic Republic of the Congo (0.03 tonnes per year), this is due to Qatar's oil exports. However, consumption-based emissions are right now slightly higher in South Africa (because of the reliance on coal for energy) than in Greece—both are around 5 tonnes per year. So the details of the answer will depend on the methodology and time frame (by 2050 China is predicted to overtake the USA as the top historical emitter).

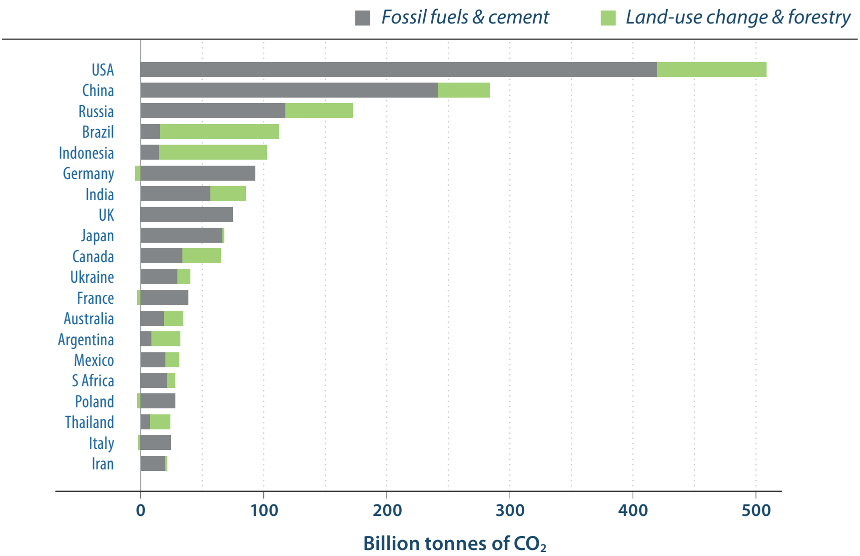
However, the current top 10 ranking **(USA, China, Russia, Brazil, Indonesia, Germany, India, UK*, Japan, and Canada)** does give a good sense of the overall picture concerning historical responsibility for climate change. See also the two figures for absolute values arranged by rank and then also by continent.



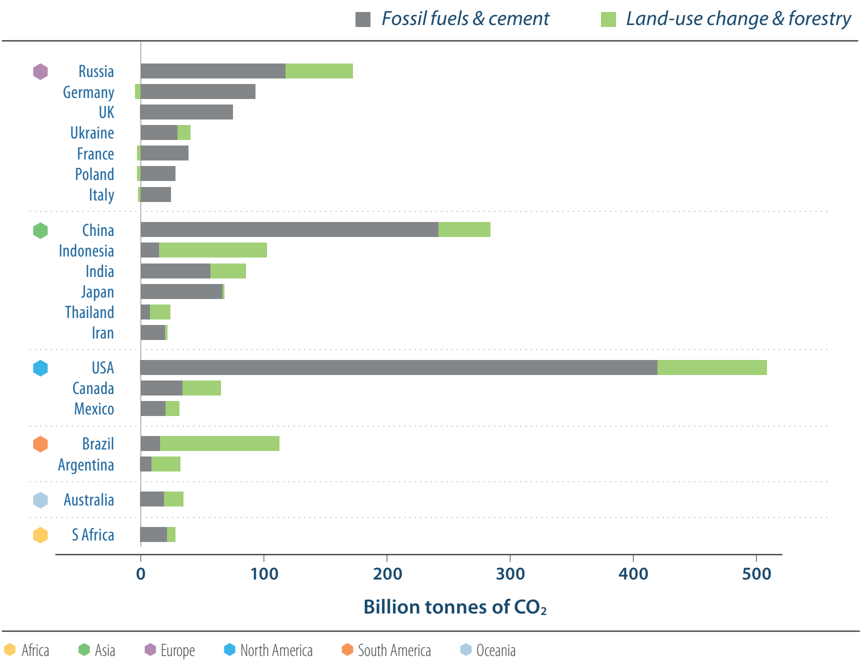
* If we account for the carbon emissions linked to the history of colonialism, the UK ranks as the 4th highest historical carbon polluter.

Cumulative CO2 emissions (1850–2021).

Source: carbonbrief.org/analysis-which-countries-are-historically-responsible-for-climate-change/

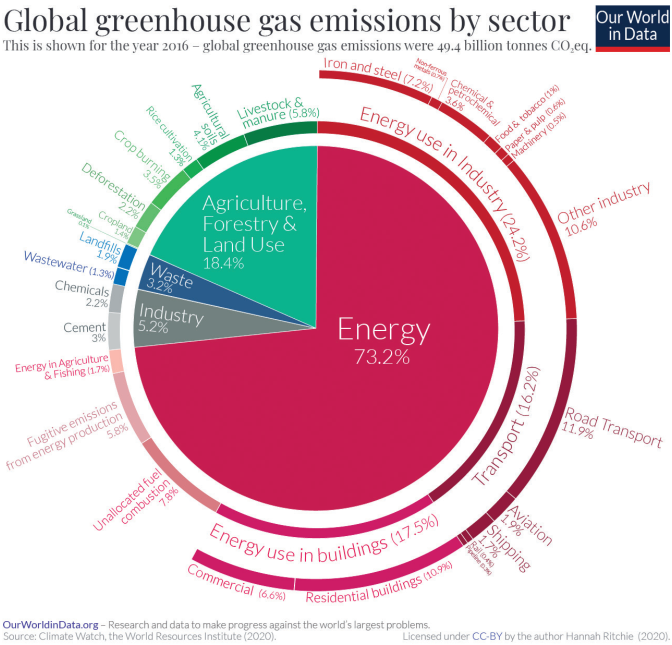


Cumulative CO2 emissions *(sorted by continent)*

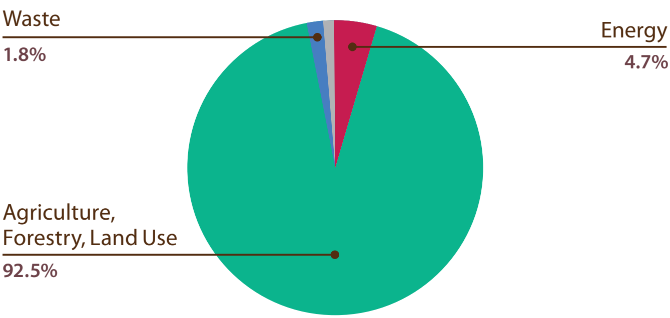


Solution 3. Trace emissions

Almost all Ugandan emissions come from land use: nearly half is a result of cutting forests (47%), cattle ranching is responsible for further 18%, converting land for pasture adds 3%, and for agriculture 13%. The distribution of sources of carbon emissions in Uganda is very different from the global average. As the world transitions towards net zero, these distributions will change.



Ugandan greenhouse gas emissions by sector:
Energy, Industry, Waste, and Agriculture, Forestry, and Land Use



Solution 4. How much money?

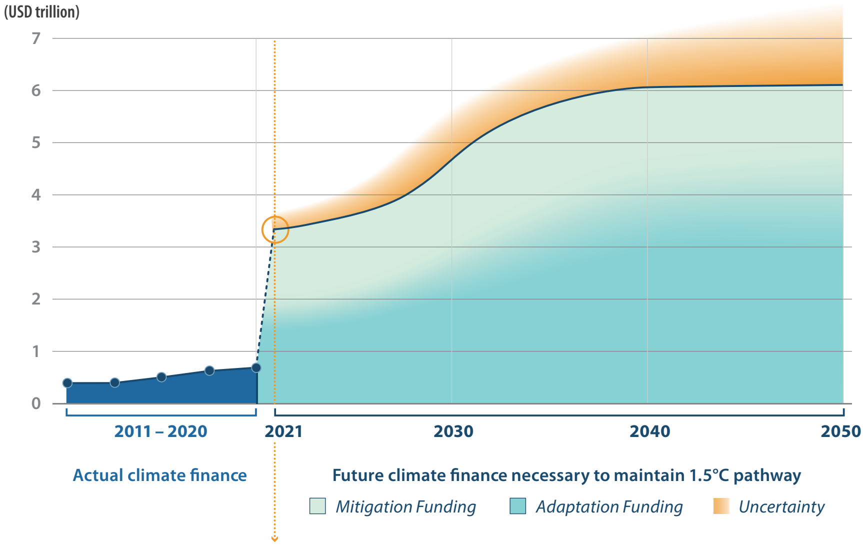
SOLUTION: SEND + MORE = MONEY is 9567 + 1085 = 10652 *(in billion $).*

As much as 11 trillion (11 000 billion) US dollars will need to be invested for climate mitigation and adaptation. Estimates vary widely depending on the definition of climate finance. Mitigation means trying to emit less greenhouse gases or take them out of the atmosphere by changing how we produce energy, how we make cement and steel, how we transport people and goods, and how we grow food. Adaptation means coping better with changes so that they don't cause as much damage to people and the environment.

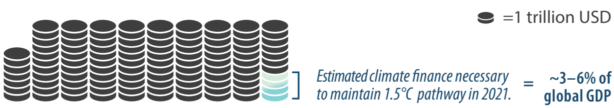
Uganda should receive billions in climate finance investments, grants, and loans—mostly for adaptation. By some estimates, the countries that used up the carbon budget (see question 2) now owe the developing countries 170 trillion dollars in compensation. This is around $1000 to every person in Uganda (and elsewhere), each year. *Source: nature.com/articles/s41893-023-01130-8*

The IPCC estimates that 3-6% of the global GDP need to be invested by 2030, which means increasing investment three- to six-fold from recent levels. Delays in climate action push up future costs; uncertainty over the level of climate finance increases with time.

Sources: the Global Landscape of Climate Finance (2021), IPCC AR6 WG3 (2022) report, Worldbank.org.



For comparison:
The Global GDP in 2021 was USD 96.1 trillion.



An example of math logic to derive the solution to the puzzle:

Notice that adding any two four-digit numbers together is always less than or equal to 19 998 (since the largest possible 4-digit number is 9 999). So to get a five-digit result (MONEY) means the digit in the M position must be 1. Then since at most S can be 9, then O must be 0 (zero). Here is why. If you look at the column addition, MO is either M + S or M + S + 1 (if 1 is carried over from adding E and O in the previous column).

Since we figured out already that M = 1, we have:

		S	**E**	**N**	**D**
+		**1**	**O**	**R**	**E**
=	**1**	**O**	**N**	**E**	**Y**

Substituting 1 for M, we know that MO = 10 + O is either (S + 1) or (S + 2) where S is at most 9 (and at least 8 since at least one of these sums must be more than 10, but with a bit more work we can rule out S = 8), so either 1O = 9 + 1 = 10 or 1O = 9 + 2 = 11, and it cannot be 11 because O is different from M, so it must be 10 where O=0).

So we have figured out three letters:

		9	**E**	**N**	**D**
+		**1**	**0**	**R**	**E**
=	**1**	**0**	**N**	**E**	**Y**

Since N is different from E, then N = E + 0 + 1 (meaning that N = E + 1), implying also that N + R has to be more than 10 (for that 1 to be carried over). Looking at the second column, either 10 + E = N + R or {10 + E = N + R + 1} if 1 is carried over from adding D + E.

Substituting E + 1 for N in {10 + E = N + R} gives R = 9 but R can't be 9 because S = 9. So {10 + E = N + R + 1} must be true, R has to be 8, and E = 5 and N = 6. Then we have:

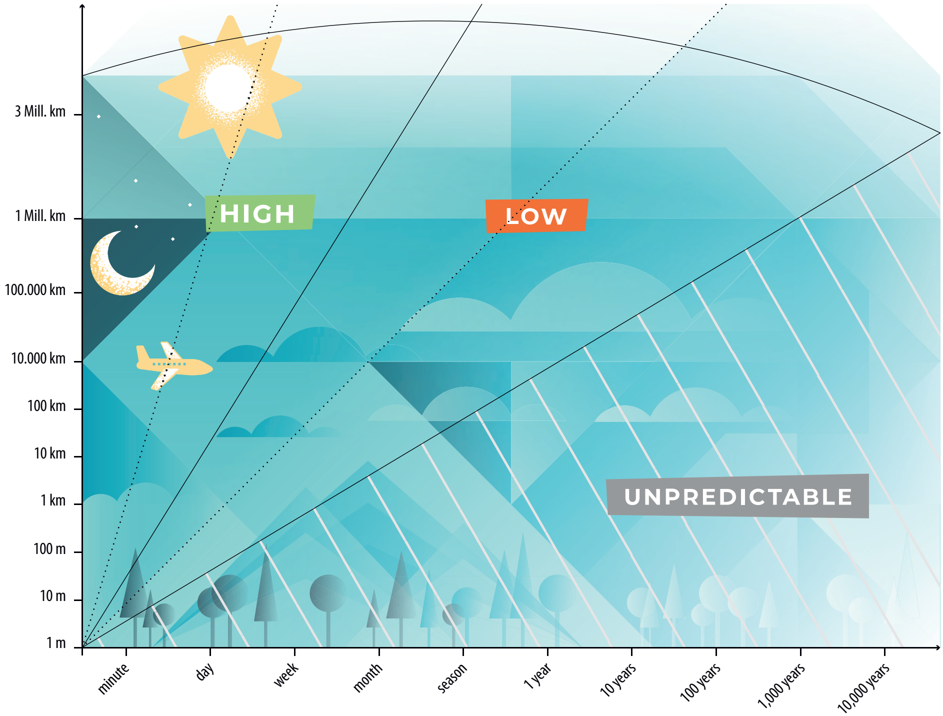
		9	**5**	**6**	**D**
+		**1**	**0**	**8**	**5**
=	**1**	**0**	**6**	**5**	**Y**

We have only {2, 3, 4, 7} left for D and Y, knowing that D + 5 = 10 + Y.
So D = 7 and Y = 2.

Solution 5. Uncertainty

Poetry, literature, art, and games can teach us a lot about uncertainty and help us to cope with anxieties and hopes about the future.

As scientists, our ability to predict what happens depends on the scale, both in time and space. We can predict the movements of comets, planets and stars way into the future. However, predicting what happens in our neighbourhoods is harder than making climate predictions on larger, global or continental scales.



Solution 6. Tipping points

Tipping points are an example of **deep uncertainty,** something that science cannot yet reliably predict but which is critically important. Poetry, science fiction, art and games can urge us to think about the risks involved, even if these are far in the future. Here is a pointedly anxious description of tipping points, from *Fifty Degrees Below*, a novel by Kim Stanley Robinson:

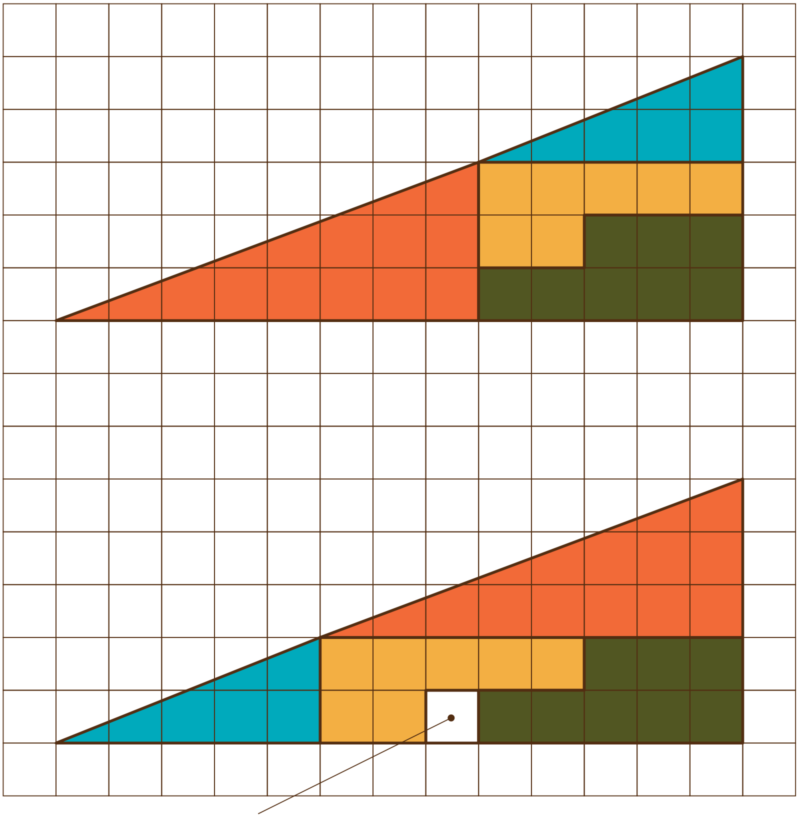
> ***They had passed the point of criticality, they had tipped over the tipping point in the same way a kid running up a seesaw will get past the axis and somewhere beyond and above it plummet down on the falling board. They were in the next mode, and coming into the second winter of abrupt climate change. (Robinson 2006)***

1. **Collapse of Ice Sheets and/or major ice formations**
   → *much higher sea levels.*
2. **Permafrost thaw releases methane**
   → *acceleration of global warming.*
3. **Massive loss of forests**
   → *loss of biodiversity & release of greenhouse gases → acceleration of global warming.*
4. **Rapid climate change**
   → *mass extinctions of animals, plants, other life forms.*
5. **Shutdown of Atlantic Meridional Overturning Circulation (AMOC)**
   → *Cooling of Northern Hemisphere*
   (AMOC conveys heat from the tropics).
6. **Increase in El Niño–Southern Oscillation (ENSO)**
   → *drought in South East Asia.*
7. **West African Monsoon**
   → *droughts across Mauritania, Senegal, Burkina Faso, Mali, and Niger.*
8. **Greening of the Sahara**
   → *greater local biodiversity.*
9. **Indian Monsoon shift**
   → *droughts on the Indian subcontinent.*
10. **Tipping points at regional level**
    → *severe local impacts on all continents.*
11. **Changed marine ecosystems**
    → *abrupt West Tropical Indian Oceanic Bloom*
    (Sudden increase in deep water upwelling brings nutrients to the upper layers of ocean, leading to gains in productivity from microorganisms to fisheries).
12. **Disappearance of coral reefs**
    → *loss of biodiversity, habitats, coastal erosion, cultural and economic losses.*

Solution 7. Climate misinformation

Answer: “Exactly 9 of these statements are false” is the only true statement. Consider alternatives and you will see why this must be the case. For example, “Exactly 7 of these statements are false” implies that there are 3 other statements that are true but that is impossible since they would contradict each other.

Of course, when it comes to climate change, you can’t always tell what is true or false just from looking at the statements—careful research may be needed!* Conversely, some phenomena that appear contradictory actually have a perfectly rational explanation—the similarity of the shapes below is an optical illusion.



How can the bottom triangle be larger than the top one?

* For the peer-reviewed collection of resources, check out: cleanet.org/clean/educational_resources/collection/index.html

Solution 8. Find solutions

Widely adopted by countries and companies, a net zero goal states that they too should be like oceans and plants: that is, release only as much carbon every year as we can store away. To clean up for historical emissions, we might need to take out more every year than we emit towards the end of this century.

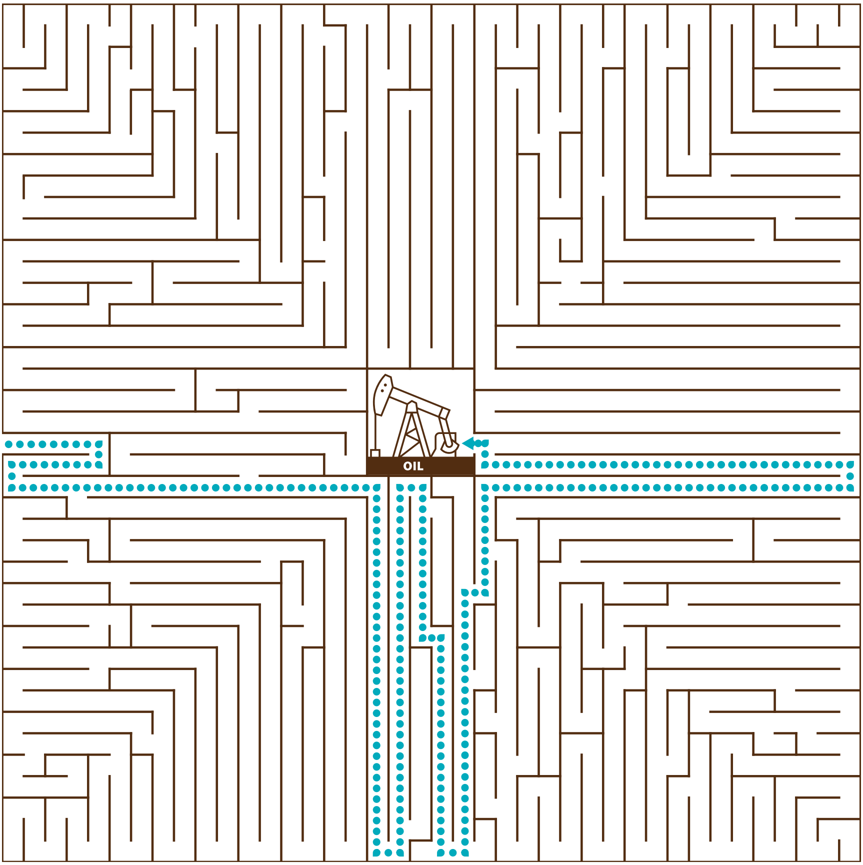
Here are some of the ways we can do this:

WORDSEARCH

N	H	V	J	R	B	I	O	C	H	A	R	I	K	D
F	B	Y	A	U	T	H	C	F	Y	B	B	X	E	O
M	I	L	M	P	S	Z	B	N	O	U	E	G	T	P
U	O	Y	S	R	K	T	U	A	N	R	R	C	R	H
S	E	U	I	F	H	B	I	T	G	O	E	F	C	I
Q	C	P	V	I	Y	X	F	C	W	G	Y	S	N	S
F	O	I	I	R	U	K	H	T	E	P	F	S	T	M
G	N	C	T	H	A	Y	H	U	L	C	I	Y	Q	S
Z	O	C	C	J	D	E	P	I	I	G	N	M	K	Z
A	M	U	A	R	K	Q	L	J	V	E	A	Q	J	O
J	Y	S	O	D	N	I	W	C	I	X	N	L	J	B
E	K	G	N	Y	H	O	P	B	U	D	C	C	T	S
Y	E	W	E	T	L	A	N	D	S	N	E	R	T	M
N	N	O	I	T	A	C	U	D	E	O	W	T	P	Z
E	L	E	C	T	R	I	F	I	C	A	T	I	O	N

Solution 9. Stranded assets

Some carbon-heavy assets can be transformed into other uses: coal power plant locations in the US are considered ideal for small nuclear stations, pipelines can carry green hydrogen instead of carbon-heavy natural gas, depleted oil and gas fields can be repurposed for CO_2 storage, and finally, carbon might be removed at source through carbon capture and storage technology at costs that leave assets viable.



Solution 10. Elders and eiders

C H A O S

C H A P S

C H I P S

S H I P S

S H O P S

S H O T S

S P O T S

S O O T S*

S O R T S

S O R E S

C O R E S

C O D E S

C O D E R

C I D E R

E I D E R

E L D E R

O L D E R

O R D E R

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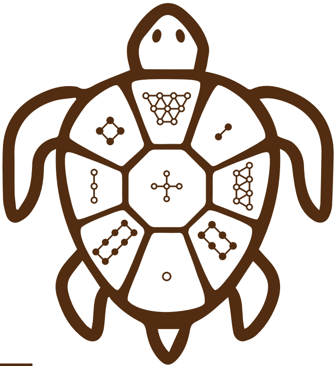
* SOOTS is another potentially tricky word. Soot is a residue, consisting mostly of carbon, a result of the incomplete combustion of wood, coal, oil, or something else being burned. Soot can also be used as a verb, to mean 'cover with soot'. He soots, he soots me not.

Solution 11. Does it add up?

Magic squares have a long history in many cultures all over the world, and have been invoked in childbirth practices, perfume-making, art and architecture. The earliest known example is a 3x3 magic square that uses consecutive numbers 1, 2, 3, 4, 5, 6, 7, 8, 9. Only one such magic square exists if one does not count rotations etc. It appears in an ancient Chinese myth about mitigating devastating floods. The myth says that after sacrifices were made to a river god, a turtle appeared to Emperor Yu with the markings of a magic square on its shell and the waters calmed:

SOLUTION:

4	9	2
3	5	7
8	1	6



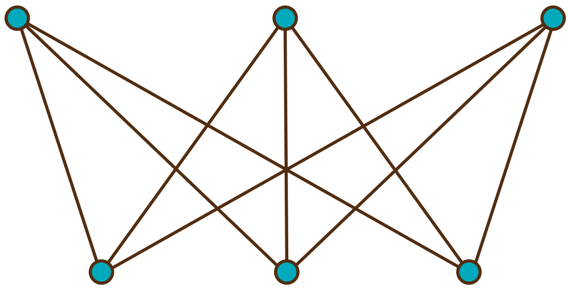
30	18	16	36
10	44	22	24
32	14	20	34
28	26	40	6

Solution 12. Perpetual growth

Sorry! This is impossible to construct, probably like a system of perpetual growth. Sometimes we need to redefine the problems before attempting a solution. Do we need to connect all houses to a national grid, e.g. why not install solar panels and make a mini-grid instead?

There is a lot of interesting mathematics hiding here. The proof that **this problem has no solution** involves Euler's formula* for maps that tell us that **F - E + V = 2** or that for any 2-dimensional shape, the number of faces (F) minus the number of edges (E) plus the number of vertices (V) is always 2. Note: don't forget to count the outside face, for example, if you draw a triangle it has two faces, one inside the shape, and the infinite one outside it. The triangle also has 3 vertices and 3 edges, so we have 2 - 3 + 3 = 2. Test the formula with a few shapes of your own.

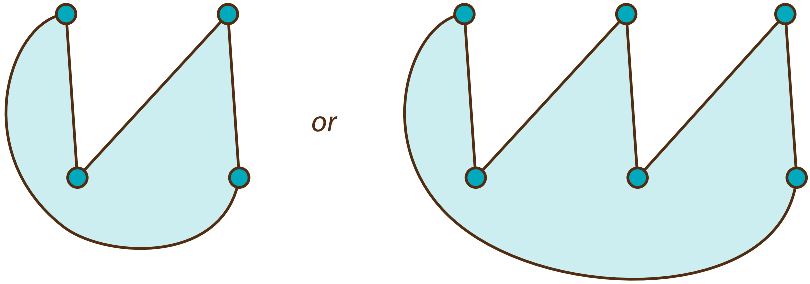
We want to show that there is no way of rearranging the lines in this equivalent problem so that they don't cross:



* There are many cool proofs of Euler's formula here is one: bit.ly/EulerProof

This is going to be a proof by contradiction *(where we assume it is possible to arrange these 9 connecting lines so that they don't intersect and derive a contradiction).* Assume it is possible and we have rearranged this so that there are no line intersections or, in other words, there are no further vertices other than the 6 we have started with. This shape will have to have 6 vertices, and 9 edges. So by Euler's formula (since $F - 9 + 6 = 2$, implies $F = 5$) it will have 5 faces, one of which is the infinite one outside the shape formed by the edges.

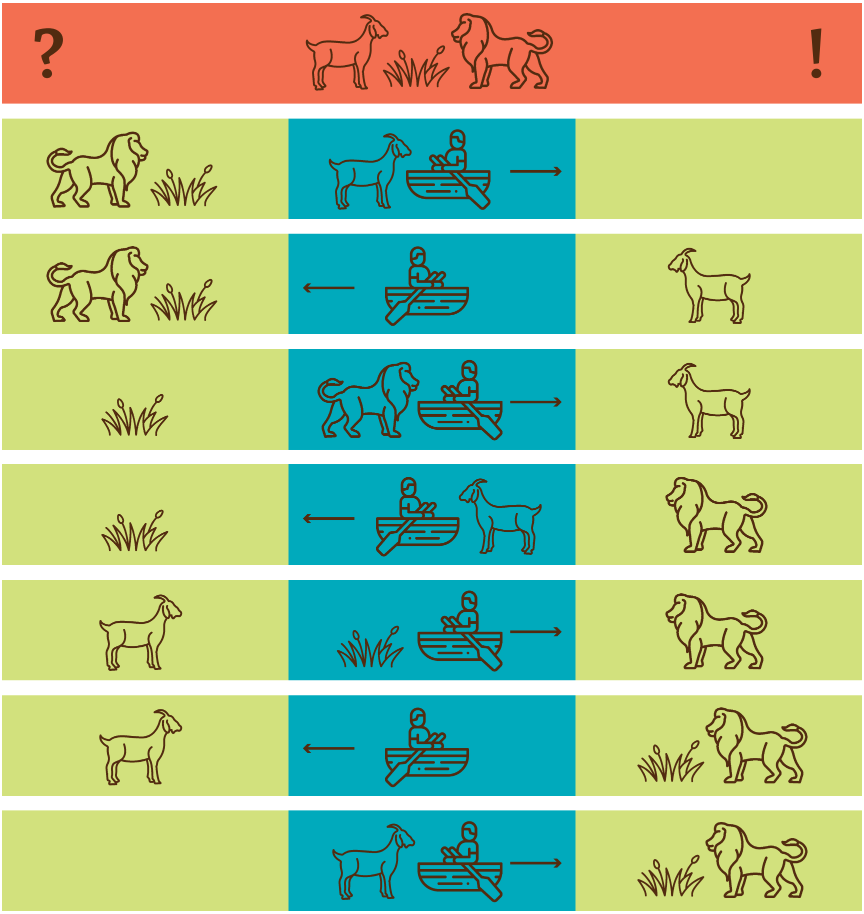
Now let's assume there are 5 faces and count the edges. Each of the 5 faces, can either have 4 or 6 edges. Why? Let's say a face contains a house as a vertex, each house is connected to a utility *but not to another house directly*, so the face must include at least two utilities and since *no utilities are connected directly to one another either,* at a minimum a face will have two houses and two utilities as vertices and thus four edges. Basically, a face can only be something like this:



So we have 5 faces, each with either 4 or 6 edges. So *the lowest* number of total edges is $5 * 4 = 20$. Each edge is shared between 2 faces, so the *minimum* number of distinct edges in the shape is 10, but we only have only **9 edges.** Contradiction!

Solution 13. Just transition

1. You take the goat across
2. Return alone
3. Take the lion across
4. Return with the goat
5. Take the grass across
6. Return alone
7. Take the goat across

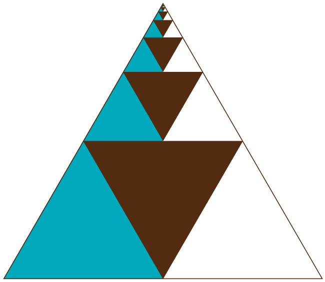


Solution 14. On the road to net zero

The total reduction is approximately ⅓.

To be precise, we need to add:
$\frac{1}{4} + \frac{1}{4} * \frac{1}{4} + \frac{1}{4} * \frac{1}{4} * \frac{1}{4} + \frac{1}{4} * \frac{1}{4} * \frac{1}{4} * \frac{1}{4}$
which is very close to ⅓—as you can guess from the picture.

In fact, if we added together all of the infinitely many terms $\{(\frac{1}{4})^n\}$ for all $\{n>0\}$ **it will be exactly ⅓.**

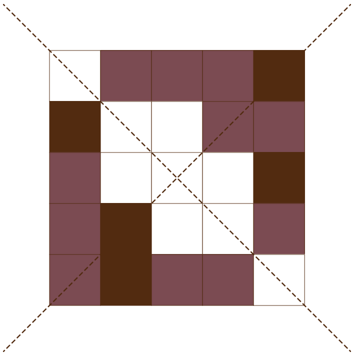


Solution 15. Biodiversity and food security

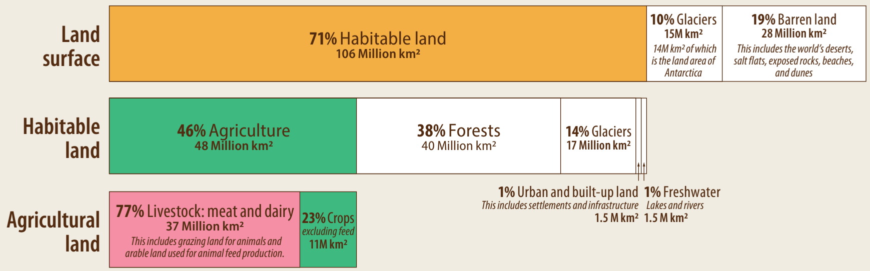
Nine squares out of 25, or roughly 36%. This is roughly the target of the Convention of Biological Diversity known as '30x30,' aimed at protecting 30% of land and sea by 2030.

In 2023, China introduced the blue book of conservation redlining, protecting 30% of its land and most ecosystem types, including mangroves and wetlands.

Note that 77% of agricultural land is used for meat and dairy which only provides 18% of calories. Thus curbing the meat and dairy industry offers a way to increase the global food supply without turning more forests into land for agriculture.



Global land use for food production

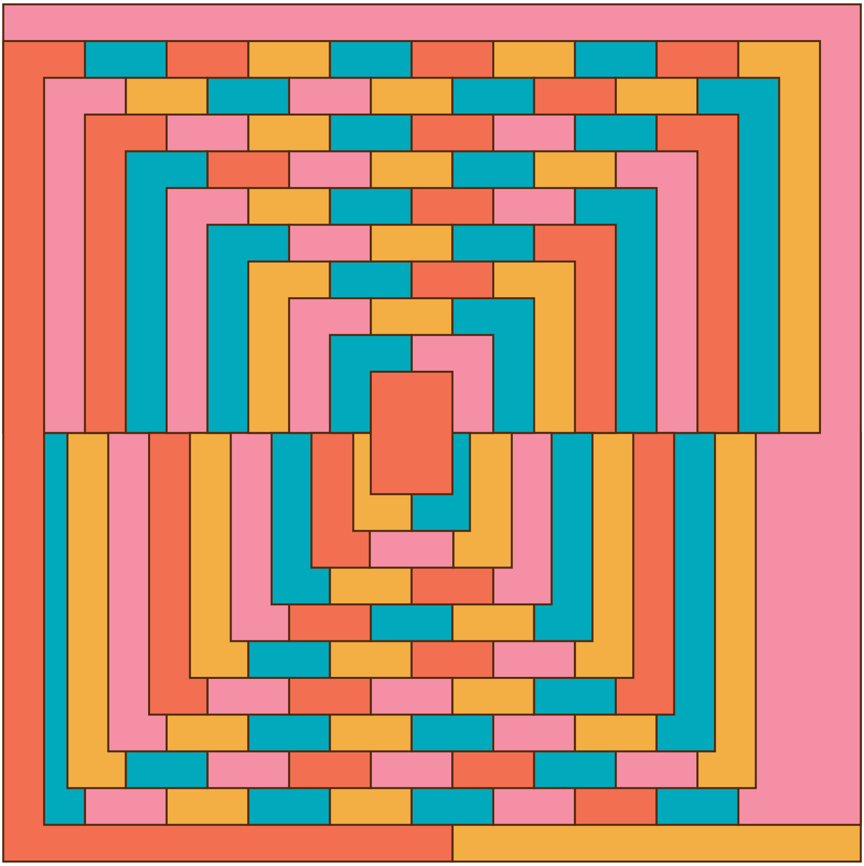


Source: Our World in Data (ourworldindata.org/land-use) | **Data source:** UN Food and Agriculture Organization (FAO)

Solution 16. Social tipping points?

D = 1 and E = 3 as $11^3 = 1331$.

Solution 17. The colour of the future



Solution 18. Global stocktaking

For simplicity, let's assume the number someone picks is larger than its reverse and has digits XYZ. Then Step 1 will give you ZYX, and Step 2 (XYZ - ZYX) or $(100 * X + 10 * Y + Z) - (100 * Z + 10 * Y + X) = 99 (X - Z)$. Since $(X - Z)$ is some whole number, the answer from Step 2 is one of the 3-digit multiples of 99, so either of these eight choices: 198, 297, 396, 495, 594, 693, 792, or 891. Step 3 will consist of reversing these, and Step 4 of adding:

$198 + 891$, or $297 + 792$, etc. Notice that in all these possible variations, the first and the last digit always add up to 9, and so the answer is $9 * 100 + 9 * 10 + 9 = 1089$ (alternatively, if you don't believe me, you can check all eight possible options).

Countries calculate emissions based on the information they collect about their economy. For example, if a country produces a lot of steel, and there is a general understanding that each ton of steel emits 3 tons of CO_2, then the emissions from that sector are three times the volume of steel that the country produces (in tons). There are similar proxies for growing food on a particular area of land, or emissions from a certain number of cars on the roads. Since most countries use national grids for electricity and know where the electricity comes from, they can estimate how much carbon was emitted (about 1 kg of CO_2 for every kilowatt hour of electricity produced by a coal power plant). Deforestation-linked emissions can be estimated using satellite data, and so forth. Uncertainties in these estimates, especially, for land-based emissions are large. Data on carbon emissions is becoming linked to an ability to secure investment, redirecting capital from data-poor to data-rich countries. Collecting, storing, and analysing emissions data itself costs money (and generates emissions) and for Uganda catching up to global data standards would mean less money to spend on health, education, or reducing emissions!