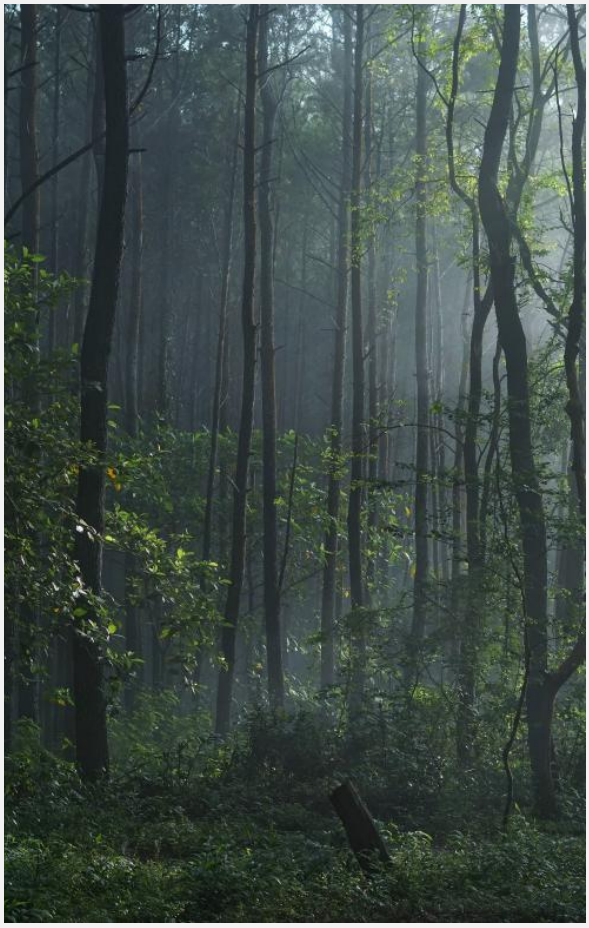
REPLANET

*RE*BOOT FOOD: THE FULL REPORT

The policy and evidence base for the Reboot Food Manifesto

Contents



About RePlanet

RePlanet is a new, charitably-funded pan-European environmental NGO with campaigners in 13 different European nations. United under the emerging philosophy of eco-humanism, RePlanet is unique among environmental NGOs for promoting the use of technologies such as advanced nuclear power, cellular agriculture and gene editing. It aims to see 50%-75% of Europe rewilded, animal farming disrupted, the climate cooled and energy abundance achieved in the Global South. RePlanet is philanthropically funded and accepts no funding from industry or political parties. Its main donor in 2022/23 was the Quadrature Climate Foundation. www.replanet.ngo // www.rebootfood.org

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Executive Summary

We are standing on the cusp of the greatest revolution in food for 10,000 years. If this revolution goes ahead, the transformation of our living planet will be as significant as that seen by our ancestors at the dawn of agriculture. But if this revolution fails, the collapse of our climate, our natural world and even our civilisations could soon be on the cards.

Agriculture as we know it now, dominated by the farming, fishing and slaughter of animals is:

- **The biggest cause of the sixth mass extinction[1] [2]**
- **Emits more greenhouse gases than the entire global transport sector[3]**
- **Uses 70% of all freshwater withdrawals[4]**
- **Caused 80% of deforestation this century[5]**
- **Slaughters 75 billion animals a year[6]**
- **Uses 28% of our planet's surface just for livestock grazing[7]**

But it doesn't have to be this way. The food revolution unfolding around us today, led by the crucial technology of precision fermentation (PF), promises a radically different future. A future in which global ecosystems regenerate to a state of flourishing not seen by humans for generations. A future in which such massive amounts of carbon have been drawn down that our climate could even be cooled back into the safe zone in which our civilisations first developed[8] .

- **Protein from microorganisms can be up to 40,900 times more land efficient than beef.**
- **Using precision fermentation we could produce the entire world's protein supply on just 420km2 – an area of land smaller than Greater London – and rewild at least 3/4s of today's farmland.**

See p20 for our calculations.

This future would not only be transformational for nature but for human society too. Managed equitably, today's food revolution promises to provide abundant nutrition to a population of 10 billion at a fraction of the cost of today's food system. With climate-resilient, geographically flexible food production, even the world's poorest and

[1] Walter Willett et al., 2019. *Food in the Anthropocene: the EAT – Lancet Commission on healthy diets from sustainable food systems*. The Lancet Commissions, volume 393, issue 10170, pp. 447-492.
[2] Brian Machovina et al., 2015. *Biodiversity conservation: The key is reducing meat consumption*. Science of The Total Environment, volume 536, pp. 419-431. https://doi.org/10.1016/j.scitotenv.2015.07.022
[3] https://ourworldindata.org/emissions-by-sector
[4] Zhongwei Huang et al., 2019. *Global agricultural green and blue water consumption under future climate and land use changes*. Journal of Hydrology, volume 574, pp. 242-256. https://doi.org/10.1016/j.jhydrol.2019.04.046
[5] Bruce M. Campbell et al., 2017. *Agriculture production as a major driver of the Earth system exceeding planetary boundaries*. Ecology and Society, volume 22, issue 4. https://doi.org/10.2307/26798991
[6] FAOSTAT, 19 February 2021. *Livestock Primary*. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/faostat/en/#data/QL
[7] https://ourworldindata.org/land-use
[8] https://www.nature.com/articles/d41586-021-01241-2

remotest communities could soon make starvation and malnutrition a thing of the past. With such an enormous opportunity, a plan to Reboot Food should be on every decision maker's desk.

The four core principles of rebooting food	
1. Make it plant-based	**2. Brew don't slaughter**
Healthy, whole and varied plant-based foods should be at the centre of everything.	Animal farming should be phased out and replaced by identical precision fermentation products wherever possible.
3. Use as little land and ocean as possible, rewild everything else	**4. Open source everything to guarantee a just transition**
High yield, low impact farming must be prioritised to make as much space for nature as possible. Farmers should be paid to rewild the spared land.	The benefits of the food revolution should be shared with all, with new technologies made open source and corporate concentration actively mitigated.

So how do we Reboot Food?

The key is a technology called precision fermentation. Thanks to recent improvements in this tried and tested technique (already used to produce 80% of global rennet[9] and 99% of global insulin[10]), food innovators have now discovered how to make animal-free proteins and fats that are biologically identical to those we currently get from cows and other livestock.

Precision fermentation allows us to move from farming macroorganisms (cows, sheep, pigs) to farming microorganisms (yeasts and bacteria). Just as our ancestors relied on microorganisms to brew beer, raise bread and ferment foods like sauerkraut or soy sauce, today's innovators have discovered how to programme microorganisms such as yeast to brew *precise* ingredients… like milk whey, egg whites or the delicious fats and proteins you get in a medium-rare steak.

Meanwhile, game-changing breakthroughs in biotech plant breeding and farm robotics mean we can now transform the farming of cereals, fruits and vegetables to be radically more land- and input-efficient, and spare even more space for nature's recovery.

[9] https://www.researchgate.net/publication/7240575_Major_Technological_Advances_and_Trends_in_Cheese
[10] Lipska, K. J., Ross, J. S., Van Houten, H. K., Beran, D., Yudkin, J. S., FRCP, & Shah, N. D. (2015, June 11). *Use and Out-of-Pocket Costs of Insulin for Type 2 Diabetes Mellitus from 2000 to 2010*. Journal of the American Medical Association (JAMA), volume 311, issue 22, pp. 2331-2333. doi: 10.1001/jama.2014.6316

However, despite the incredible promise of this new revolution, government policy is strongly rigged in favour of business as usual. Each year, $540bn is spent globally on agricultural subsidies, the majority of which goes towards the farming of animals[11]. According to the UN, 87% of this money actively harms the planet[12]. Meanwhile, public investment in precision fermentation is limited. This represents an enormous opportunity to use public money to transform our food system, before it's too late.

Policies to Reboot Food

Governments should:

1. **Invest 2.5% of GDP over 10 years into rebooting our food systems**
2. **Stop subsidies for animal agriculture, pay farmers a land-based subsidy to rewild and sequester carbon instead**
3. **Bring agriculture into the EU Emissions Trading Scheme (ETS) so emissions are capped and costed**
4. **Subsidise plant-based food at the point of sale to encourage a mass market**
5. **Implement a just transition for farmers and fishing communities**
6. **Set land use reduction and rewilding targets, suspend organic targets until yields match those of conventional agriculture**
7. **Limit patents on food innovation to 10 years and discourage corporate control**
8. **Legalise gene editing, genetic modification and other new breeding techniques**
9. **Make sustainability labelling mandatory**
10. **Ban advertising of land- and carbon-intensive animal-based foods**

[11] https://www.fao.org/documents/card/en/c/cb6562en
[12] https://www.fao.org/documents/card/en/c/cb6562en

Part 1: How food is killing the planet

An ancient story of harming planet Earth

10,000 years ago our ancestors made an astonishing leap. By moving from the old ways of hunting and gathering to domesticating plants and animals, they laid the foundations of civilisation as we know it today.

But it came at a terrible, terrible cost to the living planet.

Hunter-gatherers were not benign: they had already driven many species of megafauna to extinction. But farming required a whole new level of damage to nature. It required *land*, and lots of it.

At first, the amount of land required by farming was small and the wild ecosystems of our planet continued to thrive. But as our population skyrocketed and our diets began to get richer in land-hungry meat and dairy, farming came to devour most of the liveable space on our planet.

Today, whilst humanity's entire urban footprint covers only 1% of the Earth's land, livestock farming covers a mind-blowing 28% of the earth's surface – that's more of our planet[13] than all our forests combined. The non-human living world is left on the margins. By weight, just 4% of the world's mammals are wild, 36% are humans and 60% are livestock[14].

So why does farming's huge land use matter? Because not only could this land be used to lock up billions of tons of carbon that could help reverse[15] the climate crisis, but because the vast majority of wild species barely coexist with any form of farming at all[16] [17] [18]. Many species need large areas of completely uninterrupted wild habitat to survive[19]. A comparison

[13] https://ourworldindata.org/land-use
[14] Yinon M. Bar-On, Rob Phillips and Ron Milo, 2018. *The biomass distribution on Earth*. Proceedings of the National Academy of Sciences, volume 115, issue 25, pp. 6506-6511.
[15] https://www.nature.com/articles/d41586-021-01241-2#:~:text=Crucially%2C%20nature-based%20solutions%20cool,see%20SI%2C%20Table%20S2
[16] Andrew Balmford et al., 2018. *The environmental costs and benefits of high-yield farming*. Nature Sustainability, volume 1, pp. 477–485. https://doi.org/10.1038/s41893-018-0138-5
[17] David P. Edwards et al., 2015. *Land-Sparing Agriculture Best Protects Avian Phylogenetic Diversity*. Current Biology, volume 25, issue 18, pp. 2384-2391. https://doi.org/10.1016/j.cub.2015.07.063
[18] Ben Phalan et al., 2011. *Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared*. Science, volume 333, issue 6047, pp. 1289-1291. https://doi.org/10.1126/science.1208742
[19] M. Pfeifer et al., 2017. *Creation of forest edges has a global impact on forest vertebrates*. Nature, volume 551, pp. 187–191. https://doi.org/10.1038/nature24457

between even an organically farmed field and a truly wild ecosystem clearly shows which one nature needs more of.

No wonder then that food production is the single greatest cause of the ongoing sixth mass extinction[20] [21]. Farming, over the last 10,000 years, has brought our planet to the point of collapse. It's time to reboot this outmoded industry.

Farming Version 1 Scorecard

- **The biggest cause of the sixth mass extinction[22] [23]**
- **Emits more greenhouse gases than the entire global transport sector[24]**
- **Uses 70% of all freshwater withdrawals[25]**
- **Caused 80% of deforestation this century[26]**
- **Slaughters 75 billion animals a year[27]**
- **Uses 28% of our planet's surface just for livestock grazing[28]**

Land, land, land

The single biggest problem with agriculture today is land use. Put simply, we use far too much land to produce our food and, because the vast majority of species simply cannot coexist with any form of extractive industry[29] [30] [31], wild nature is running out of space to exist. Despite this, many well-meaning environmental policies are set to make this problem worse.

Throughout the second half of the 20th century, researchers documented that farmland wildlife was declining due to the increasing industrialisation of agriculture. As a result of their work, many well-intentioned governments and NGOs came to prescribe less intensive

[20] Walter Willett et al., 2019. *Food in the Anthropocene: the EAT – Lancet Commission on healthy diets from sustainable food systems*. The Lancet Commissions, volume 393, issue 10170, pp. 447-492.
[21] Brian Machovina et al., 2015. *Biodiversity conservation: The key is reducing meat consumption*. Science of The Total Environment, volume 536, pp. 419-431. https://doi.org/10.1016/j.scitotenv.2015.07.022
[22] Walter Willett et al., 2019. *Food in the Anthropocene: the EAT – Lancet Commission on healthy diets from sustainable food systems*. The Lancet Commissions, volume 393, issue 10170, pp. 447-492.
[23] Brian Machovina et al., 2015. *Biodiversity conservation: The key is reducing meat consumption*. Science of The Total Environment, volume 536, pp. 419-431. https://doi.org/10.1016/j.scitotenv.2015.07.022
[24] https://ourworldindata.org/emissions-by-sector
[25] Zhongwei Huang et al., 2019. *Global agricultural green and blue water consumption under future climate and land use changes*. Journal of Hydrology, volume 574, pp. 242-256. https://doi.org/10.1016/j.jhydrol.2019.04.046
[26] Bruce M. Campbell et al., 2017. *Agriculture production as a major driver of the Earth system exceeding planetary boundaries*. Ecology and Society, volume 22, issue 4. https://doi.org/10.2307/26798991
[27] FAOSTAT, 19 February 2021. *Livestock Primary*. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/faostat/en/#data/QL
[28] https://ourworldindata.org/land-use
[29] Andrew Balmford et al., 2018. *The environmental costs and benefits of high-yield farming*. Nature Sustainability, volume 1, pp. 477–485. https://doi.org/10.1038/s41893-018-0138-5
[30] David P. Edwards et al., 2015. *Land-Sparing Agriculture Best Protects Avian Phylogenetic Diversity*. Current Biology, volume 25, issue 18, pp. 2384-2391. https://doi.org/10.1016/j.cub.2015.07.063
[31] Ben Phalan et al., 2011. *Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared*. Science, volume 333, issue 6047, pp. 1289-1291. https://doi.org/10.1126/science.1208742

farming methods as a way of making farming more nature-friendly. This approach has gained ground and is now enshrined in the policies of the EU's Farm to Fork strategy under a plan to make EU agriculture 25% organic by 2030[32].

But there's a big problem. As a general rule, the more nature-friendly you try to make farming, the lower the yields. The lower the yields, the more land you need to produce the same amount of food. The more land you need, the less space there is for truly wild nature, which has far greater biodiversity than any farmed landscape.

Roughly speaking, this is the debate between 'land-sparing' and 'land-sharing'. To settle it, in the biggest study of its kind ever completed, a team led by Professor Andrew Balmford at the University of Cambridge compared 2,500 data sets from five continents. Their findings were the same wherever they ran the numbers. Non-human species *always* fare better where farming is concentrated onto the smallest amount of land possible, as opposed to where farming sprawls and tries to share space with nature[33].

And this approach isn't just good for biodiversity, it's great for the climate too. One paper found that by rapidly phasing out animal agriculture and rewilding the land used currently, the world could offset 68% of its CO2 emissions this century[34].

With such an unequivocal conclusion, it has become a moral imperative for humanity to use less land for farming and leave more free for nature. Thankfully, we now have the technologies and methods to do this without sacrificing our own food security.

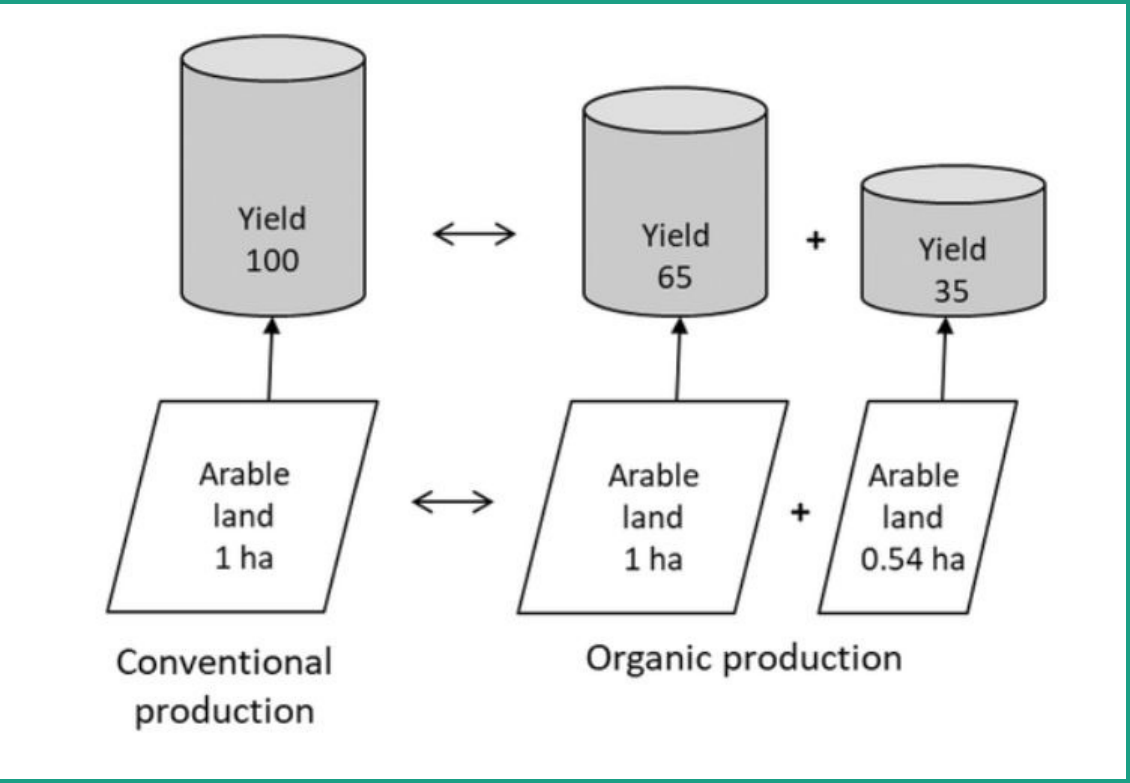
But organic farming is good, right?

Sadly, it's not that simple. Organic farming, at least as it is widely practised today, uses a lot more land than conventional farming.

On average, an organic field produces 35% less food per acre than a conventional farm[35]. So does that mean you need 35% more land? No, in fact you need 54% more land[36]!

Why? Because the additional land you bring into production to fill these yield gaps will, if organic, *also* have lower yields, so you'll need more of that land to make up the difference. This graphic explains it pretty well:

[32] https://www.consilium.europa.eu/en/policies/from-farm-to-fork/
[33] Andrew Balmford, 2021. *Concentrating vs. spreading our footprint: how to meet humanity's needs at least cost to nature*. ZSL Journal of Zoology. https://zslpublications.onlinelibrary.wiley.com/doi/full/10.1111/jzo.12920
[34] https://journals.plos.org/climate/article?id=10.1371%2Fjournal.pclm.0000010
[35] https://journals.sagepub.com/doi/full/10.1177/0030727019831702
[36] https://journals.sagepub.com/doi/full/10.1177/0030727019831702



Organic farming also rules out the use of new breeding techniques (read more about these in Part 2), not on the basis of any scientific evidence of their harm, but as a legacy of the unscientific opposition to the introduction of genetic engineering 20 years ago.

As we detail in Part 2, biotech crops can help achieve many of organic agriculture's aims, such as lower synthetic fertiliser and pesticide use, whilst also achieving high yields and greater climate resilience.

But it's also not as simple as writing off organic. There are some innovative methods of high-yield organic being trialled that could achieve yields sufficient to spare land for nature. Equally, as we outline in Part 2, an 'organic biotech' method could be the best of both worlds.

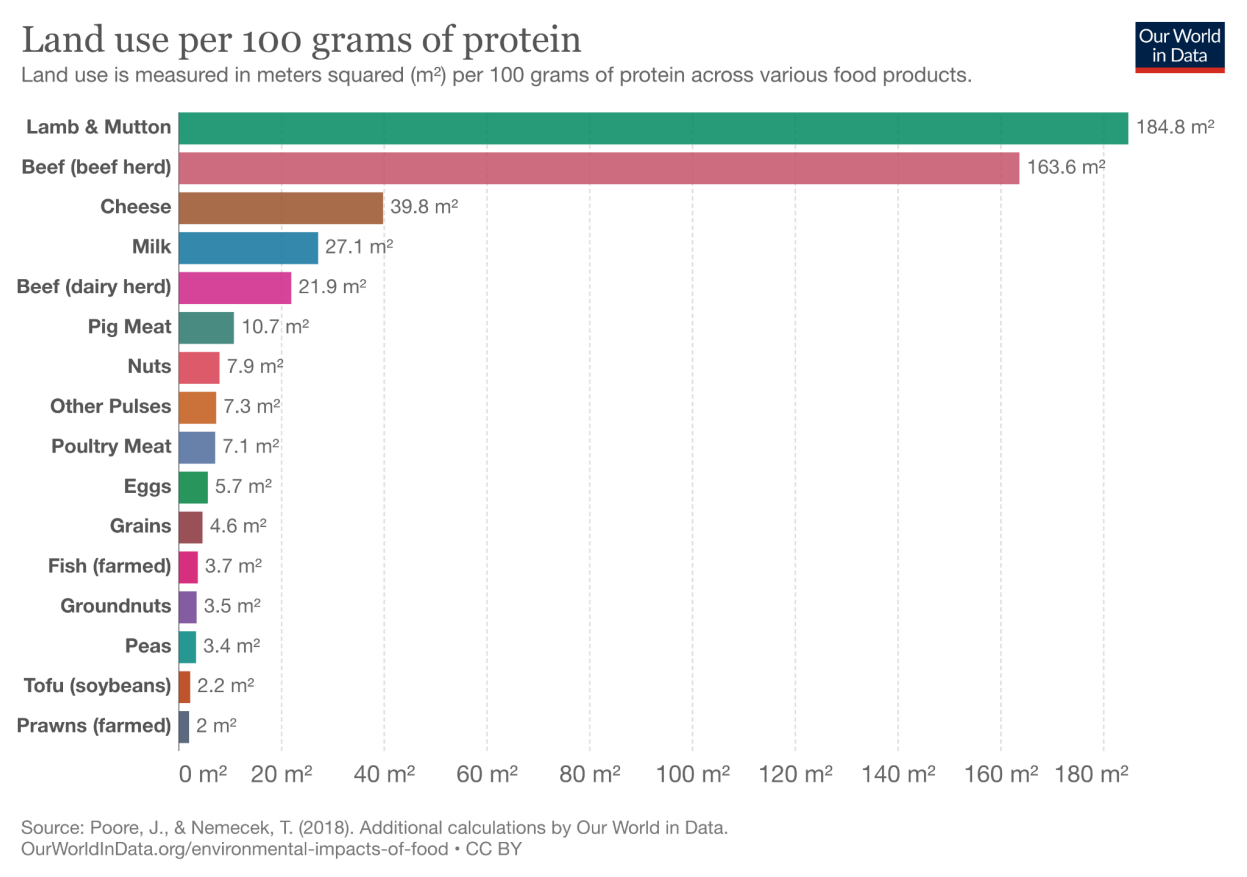
Animals, animals, animals

With land use our overriding environmental priority, the most urgently needed reboot of today's farming is in its use of animals. Animal agriculture is, by almost every metric, the most damaging and least efficient sector of today's food system.

Whilst human habitation covers just 1% of the planet and 12% is crops, an extraordinary 28% of the planet is given over to the grazing of livestock[37]. And yet, animals fed by grazing pasture alone produce only 1% of the world's protein[38]. This is a staggeringly inefficient use of our most important natural resource.

The reason behind this is simple. Animals themselves don't create protein. They recycle amino acids (the building blocks of proteins) from plants, via digestive processes based around microorganisms in their guts. But this recycling process is far from efficient. The animal itself needs to live, and as a result large amounts of metabolic energy are already expended by the time a human comes to eat them.

The result of this inefficient recycling is that the farming of animals needs much more land than the farming of plants to produce the same number of calories – proteins included. You need, for example, 75 times less land to produce 100 calories of tofu than 100 calories of beef, while both are nutritionally complete forms of protein[39].



[37] https://ourworldindata.org/land-use
[38] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2007GB002952
[39] https://ourworldindata.org/grapher/land-use-kcal-poore

But even if there wasn't a land use issue, phasing out animal agriculture should already be a priority, if only for the sake of animal welfare and human health.

But what about pasture-fed beef? Isn't that meant to draw down carbon somehow?

In a word: no. There's a lot of myths – and deliberate misinformation – around about grass-fed beef being somehow good for the planet by enriching soils with carbon. Many of those in the livestock industry have advocated for *more* livestock farming by claiming it will help reverse climate change. But the vast majority of the peer-reviewed scientific literature tells a different story.

One of the leading studies in this area concluded that even the best examples of pasture-fed beef can only absorb up to 60% of the greenhouse gas emissions that farming releases[40]. In short: pasture-fed beef can't even absorb its own emissions, let alone draw down carbon from the atmosphere.

Welfare

Animal farming, no matter how you advertise it, is horrific for the animals. The majority of farmed animals are kept in factory farms[41], but even those that aren't still endure great hardships and have their lives cut short by slaughter. Farmed animals are routinely mutilated (with teeth, tails and horns cut off), forcibly inseminated, deprived of sensory stimulation, separated from their own young and worked to an early grave[42].

The average dairy cow should naturally live to around 20 years and, when suckling her own young, produce just 4 litres of milk a day[43]. In a standard commercial farm however, such a cow will be forcibly inseminated year after year, her young will be separated from her just days after birth and she will be milked for 30 litres of milk a day (the US average) or up to 60 litres at maximum lactation[44]. The majority of such cows will suffer mastitis, a painful bacterial infection of the udder caused by unsanitary equipment, and many will become emaciated or lame through over-milking. After this painful, exhausting existence, the average dairy cow will be slaughtered at just six years old[45].

Such practices are found in almost every aspect of animal farming, and yet today an increasingly prosperous global human population is eating *more*, not less, meat, dairy and

[40] https://www.oxfordmartin.ox.ac.uk/downloads/reports/fcrn_gnc_report.pdf
[41] https://www.sentienceinstitute.org/us-factory-farming-estimates
[42] https://www.ciwf.org.uk/factory-farming/animal-cruelty/
[43] Mohd Nor, N., Steeneveld, W., & Hogeveen, H. (2013). The average culling rate of Dutch dairy herds over the years 2007 to 2010 and its association with herd reproduction performance and health. Journal of Dairy Research, 1-8
[44] https://www.ciwf.org.uk/farm-animals/cows/dairy-cows/
[45] https://www.ciwf.org.uk/media/5235185/the-life-of-dairy-cows.pdf

seafood[46]. But the horrendous reality of this situation requires pragmatism, not idealism. Trends towards vegetarianism or veganism in the wealthy Global North are nowhere near fast enough to compensate for the vast rise in meat consumption projected in the Global South. If we want to end these moral horrors in time to save our planet, we need to find a way to produce identical animal products without the animals. Thankfully, these technologies already exist.

The advent of widely scaleable animal product analogues from precision fermentation fundamentally changes our moral relationship with animals. No matter how good the welfare provisions are, most people would surely agree it would be better not to kill or exploit animals at all if we can produce identical products by a different route.

[46] https://ourworldindata.org/meat-production

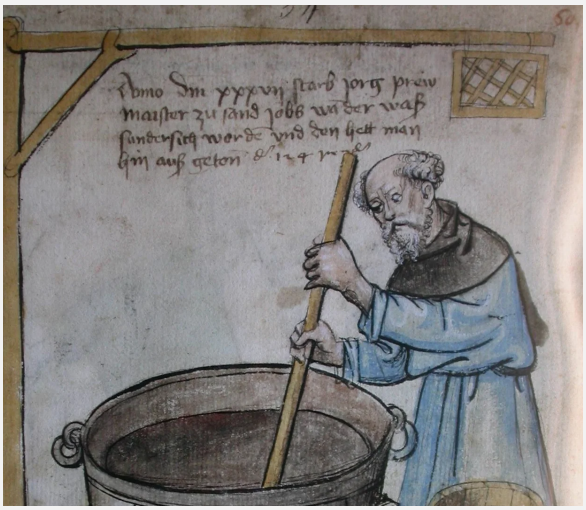
Part 2: How to Reboot Food

A new story of regeneration, thanks to an ancient method

If the last 10,000 years was an age of extreme environmental harm, the next 10,000 could be an age of unprecedented natural recovery. It may not feel like it, but today we are living in a moment that could be as revolutionary as the beginning of settled agriculture.

Whilst the emergence of farming has come to radically damage global ecosystems at a scale unimaginable to the first agrarians, today's food revolution has the potential to do the opposite: restoring nature at a scale far greater than could be achieved by the actions of any individual, government or corporation.

The difference this time all comes down to microorganisms – the trillions of incredibly diverse life forms that exist in our soil, our air and our own bodies. Put simply, whilst our ancient ancestors discovered how to farm macroorganisms (like wheat, barley, aurochs and goats), today's food innovators have unlocked the biological keys to farm microorganisms and to work with nature at a cellular level. As we explain in this section, this simple change has profound consequences for almost every aspect of society.



If decision makers lean into this revolution, making policies that pave the way rather than hinder it, our children and grandchildren could soon live in a world in which food poverty is an object of historical fascination, and flourishing wild ecosystems are a matter of everyday experience.

For those of us alive today, the next decades could be a time of astonishing ecological creativity, as we mobilise our communities to rewild, restore and regenerate nature on the vast swathes of land freed up from the outmoded animal-based agriculture of the past.

Principles of rebooting food

The four core principles of rebooting food	
1. Make it plant-based	**2. Brew don't slaughter**
Healthy, whole and varied plant-based foods should be at the centre of everything.	Animal farming should be phased out and replaced by identical precision fermentation products wherever possible.
3. Use as little land and ocean as possible, rewild everything else	**4. Open source everything to guarantee a just transition**
High yield, low impact farming must be prioritised to make as much space for nature as possible. Farmers should be paid to rewild the spared land.	The benefits of the food revolution should be shared with all, with new technologies made open source and corporate concentration actively mitigated.

Innovations to Reboot Food

Innovation is not something to reject out of hand as a 'techno-fix'. Technology has, throughout history, played an intertwining role with ethics in creating 'techno-ethical shifts'. A recent example is the contraceptive pill and the host of societal, moral and cultural changes that came with its introduction.

While moral suasion can convince some people to change their diets, widespread access to affordable and identical animal-free alternatives is the missing piece to unlock a transformation of our food systems scalable enough to save our planet. Technological disruption can be rapid, non-linear and irreversible – just think of the early 20th century transition from horses to automobiles.

However, with large technological disruption comes the risk of corporate concentration (think Facebook, Uber etc). While the technologies we support promise enormous benefits to humanity and the planet, they also threaten a dangerously insecure and unequal future if our food supply becomes controlled by a small number of mega-companies utilising integrated global supply chains and massive economies of scale. This outcome must be resisted by citizens and actively mitigated by governments through public funding and ownership (see more in our policy prescriptions below). Here are the technologies we need to Reboot Food:

Precision fermentation

Precision fermentation is a refined form of brewing that uses microorganisms to make ingredients we currently get from animals or plants. While our ancient ancestors made bread, cheese and beer by using the microorganisms that were randomly present in their environment, today's precision fermentation can genetically reprogramme microorganisms to make exact nutrients. Here's how to do it:

1. **Choose a specific microorganism such as a yeast or bacteria.**
2. **Genetically engineer the microorganism with the DNA sequences coding for the amino acids which form the protein you want to create – such as the proteins found in cow's milk: casein and whey.**
3. **Put the microorganisms in a fermentation tank with some simple nutrients and sugars.**
4. **Ferment! (Just like beer.)**
5. **Harvest food-grade ingredients that are biologically identical to those you'd get from an animal and mix them up into sellable familiar products (like dairy milk, cream or cheese…).**

Precision fermentation has already disrupted and replaced animal products on a global scale. In the first half of the 20th century, insulin – a protein used to treat diabetics – was harvested from the pancreases of cows and pigs. This process required a staggering 50,000 slaughtered animals to produce just 1 kg of the hormone.

But in the late 1970s, a company called Genentech found a way of creating human insulin using precision fermentation with a human DNA sequence in yeast. Being cheaper and better in quality, it quickly captured the market. Today, PF insulin accounts for 99% of insulin demand worldwide, saving millions of lives – both of diabetic humans and of cows and pigs which would otherwise be killed. A similar story happened with rennet, a crucial ingredient in cheese, formerly harvested from the stomach linings of calves.

But in just the last decade, precision fermentation innovators have made the next crucial leap, into commercialising PF versions of familiar kitchen ingredients.

INSULIN

99% of global demand now supplied by precision fermentation[47]

RENNET

80% of global demand now supplied by precision fermentation[48]

Producing the entire world's protein

In writing this report we made two astonishing discoveries.

1. **Protein from microorganisms, powered with wind power, can be up to 40,900 times more land efficient than beef.**

Here's how we calculated this: The land use of bacterial protein depends on the energy source being used to power the production facility in which it is brewed. If solar power is used, bacterial protein has a land use of 0.18-0.26 m2/kg of protein/year. If wind power is used the land-use decreases to around 0.04 m2/kg of protein/year.[49] If nuclear power were used it is likely that this number would be even smaller. By comparison, beef land use is dramatically higher at 1636m2/kg of protein[50]. So if we divide the land use of beef (1636m2/kg-1) by that of wind powered bacterial protein, the lowest land use for which we have reliable data (0.04m2/kg-1) we get a multiplier of 40,900.

2. **Using precision fermentation we could produce the entire world's protein requirements on just 420km2 - an area of land smaller than Greater London- and rewild at least 3/4s of today's farmland.**

[47] Kasia J. Lipska, Joseph S. Ross and Holly K. Van Houten, 2014. *Use and Out-of-Pocket Costs of Insulin for Type 2 Diabetes Mellitus From 2000 Through 2010*. Journal of the American Medical Association (JAMA), volume 311, issue 22, pp. 2331-2333. https://doi.org/10.1001/jama.2014.6316
[48] Jeanne Yacoubou, 21 August 2012. *Microbial Rennets and Fermentation Produced Chymosin (FPC): How Vegetarian Are They?* The Vegetarian Resource Group (VRG).
[49] https://www.sciencedirect.com/science/article/pii/S221191241830141X?via%3Dihub
[50] https://ourworldindata.org/grapher/land-use-protein-poore

How we calculated this: The wet weight protein content of soybeans is roughly 17%. USDA figures show 120m tonnes of soybean harvested in the US/yr-1, so = 20.4mt/protein/yr-1. The total global protein requirement is 146 mt/yr-1. So US soy provides 14% of global protein. Tomas Linder reports that the equivalent amount of dry bacterial biomass could be produced on a land area of 210km2[51].

Protein content of this biomass is roughly 60%, so land area required for protein equivalent to US soy crop is 28% that of equivalent soy biomass = 58.8km2. If that provides 14% of total global requirement, total global protein requirement could be met on 420km2. As above we also need to account for land use for processing facilities and clean electricity generation, which varies widely.

This leaves over 1,000 km2 for processing plants and energy production. For an indicative example of how little land energy production could require, our calculations suggest that the UK's entire 2050 electricity demand could be met with nuclear energy covering just 48km2[52]. Since Greater London's surface area is 1,569km2, this therefore allows more than enough space to account for all production, processing and energy demand for the entire world's protein needs.

This incredible land efficiency could transform our planet and provide abundant space for wild nature. Our World In Data calculates that with a fully vegan global diet, global agricultural land use could be reduced from 4 to 1 billion hectares. But precision fermentation could take us even further. Precision fermentation can be used to produce many plant derived foods such palm oil, citric acid and vanilla essence meaning that one could plausibly reduce land use even lower than a purely plant based diet.

[51] https://doi.org/10.3389/fsufs.2019.00032

[52] Example: Hinkley Point C. Area, km^2: 1.70. Capacity, GW: 3.26. Capacity factor, %: 85%. Electricity generation, TWh/yr: 24.3. Spatial efficiency, km^2 per TWh: 0.07. UK 2050 electricity demand: 681 TWh. Area needed to power entire 2050 demand: 48km2

Precision fermentation products already on the market and available to buy today:

PRODUCT: **MILK**
COMPANY: **PERFECT DAY DAIRY**

Perfect Day is a Californian company producing animal-free versions of the two crucial proteins in milk: casein and whey. You can buy milk made from this throughout the US under the Bored Cow brand.

PRODUCT: **GROUND BEEF**
COMPANY: **IMPOSSIBLE**

Impossible Foods make 'burgers that bleed' using a precision fermentation product called heme. Heme, a plant-type variant of haemoglobin, is the iron-based molecule found in blood that makes meat taste like meat. It is now widely available in the US.

PRODUCT: **EGG WHITES**
COMPANY: **THE EVERY COMPANY**

The Every Company has used PF to crack the codes to create identical egg whites – just without chickens. In March 2023 they launched their first PF-enabled macaroons with leading French pastry chef Chantal Guillon.

PRODUCT: **CREAM**
COMPANY: **BRAVE ROBOT**

Brave Robot makes a range of ice cream flavours using animal-free milk proteins created by Perfect Day. Already available in the US, it has plans to expand internationally.

Today, precision fermentation is one of the most rapidly advancing areas of food innovation. Cheese, steak, fish and almost every animal product we use today is now technologically feasible with PF.

Precision fermentation products reaching the market:

PRODUCT: **STEAK**
COMPANY**: MEATI**

Meati from Boulder, Colorado are making precision fermentation enabled meats from mycelium.

PRODUCT: **CHEESE**
COMPANY: **FORMO**

Formo is a start-up from Berlin using precision fermented milk proteins to make a range of cheeses that melt, stretch and cook just like 'real' cheese.

PRODUCT: **PROTEIN POWDERS**
COMPANY: **SOLEIN**

Solein, by Solar Foods in Finland, is making a complete protein powder with a microorganism that uses hydrogen split from water using the power of solar PV then fermented with nutrients and CO2. Initial life cycle assessments suggest this could be the most ecologically-friendly protein ever produced.

Environmental impacts of precision fermentation

On every metric of environmental impact, precision fermentation is an order of magnitude better than equivalent animal-derived products, with specific products using up to 90% less land,[53] 91% less greenhouse gas emissions[54] and 96% less water consumption.[55]

Biotech breeding techniques

Macroorganisms such as plants can also be engineered at a cellular level. New technologies in particular CRISPR, plus other forms of gene editing offer the potential to make crops more climate resilient, while using less land and less pesticides[56] [57]. Many of the objectives of organic agriculture (such as farming without synthetic pesticides and fertiliser) could be achieved more effectively with genetically modified crops[58] [59]. Although there is a robust scientific consensus that conventional breeding and biotech breeding techniques are equally safe[60], regulations on biotech crops are far more restrictive. Biotech breeding techniques are able to solve problems that conventional breeding cannot by accessing a much broader pool of genetic traits, for example even potentially turning non-nitrogen-fixing plants into nitrogen-fixing ones, greatly reducing fertiliser needs.

Robotics, mapping and indoor farming

In the world of conventional agriculture for plant products, we could massively increase our yields and reduce the runoff of fertilisers and pesticides if we understood our soils better, could better protect them, and could choose precisely which soils should be farmed and which should be spared for nature. New mapping techniques mean that we could soon map the soils of planet Earth in high definition, allowing precise inputs of required amounts of nutrients only. Meanwhile, the expansion of robot weedkillers could open up no-till farming techniques that leave the soil undisturbed without resorting to widespread herbicide use. Indoor farming with single storey greenhouses can also massively increase yields and spare more land[61].

But what about cultivated meat?

Cultivated meat (also known as 'cultured', 'clean' or 'lab-grown' meat) is a different technology from precision fermentation.

While precision fermentation uses microorganisms to create specific proteins and

[53] https://www.nature.com/articles/s43016-021-00418-2
[54]https://m4f6w9b2.rocketcdn.me/app/uploads/2022/01/Comparative-Perfect-Day-Whey-LCA-report-prepared-by-WSP_20AUG2021_Non-Confidential-1.pdf
[55]https://m4f6w9b2.rocketcdn.me/app/uploads/2022/01/Comparative-Perfect-Day-Whey-LCA-report-prepared-by-WSP_20AUG2021_Non-Confidential-1.pdf
[56] https://www.nature.com/articles/s41467-020-20122-2
[57] https://www.frontiersin.org/articles/10.3389/fbioe.2018.00106/full?&utm
[58] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0111629
[59] https://www.nature.com/articles/s41598-020-65684-9
[60] https://www.sciencedirect.com/science/article/pii/S2590262819300024
[61] https://www.freshplaza.com/article/9385995/the-netherlands-tomato-yield-per-acreage-is-13-times-higher-than-the-spanish-yield/

fats, cultivated meat takes actual animal cells harvested from a live animal and multiplies them in a bioreactor to create animal flesh. Such food has very nearly made it onto the market, with cultivated chicken nuggets going on sale in Singapore, but serious concerns remain about its costs and therefore economic scalability[62].

Such concerns are driven by the need for pharmaceutical-grade aseptic conditions required to hygienically produce large quantities of animal tissue, and the viability of bio-scaffolding to mimic muscle fibre[63].

Whether such obstacles can be overcome will be determined only with significantly more research and continued funding, ideally led by the public sector. But in the meantime, with precision fermentation already a tried-and-tested scalable technology capable of producing all the fats and proteins currently obtained from animals, RePlanet believes that cultivated meat is simply not needed as a precondition to completely reboot our food systems.

A just transition for farmers and fishing communities

It is self-evident that farmers and those employed in associated industries are not, in general, suited to reskilling as precision fermentation engineers or the other roles that will be needed as the food revolution unfolds. It is also obvious that modern food production will be most economical in concentrated factories, not distributed up muddy tracks in remote bits of the countryside. In short, it is crucial that decision makers don't delude themselves that the food revolution will be anything short of historically transformative and disruptive for livestock farmers and their communities.

However, a moment of such significant change is also a moment of immense opportunity. Today's farming and fishing communities are already being buffeted by some or all of the following: climate-induced extreme weather, rising input costs, low farmgate prices, labour shortages, declining mental health, the impact of international trade deals, ageing farming populations and rising farm conglomeration. With such unfavourable odds stacked against them, many farmers are already outspoken about the need for a paradigm shift in how their industry is supported and regulated.

This places a huge burden on decision makers today to protect the livelihoods, families and communities of those that will be most exposed to the disruption caused by precision fermentation. Leaving farmers to face the collapse of their business model is unthinkable and would have devastating social consequences,

[62] Lieven Thorrez and Herman Vandenburgh, 2019. Challenges in the quest for 'clean meat'. Nature Biotechnology, volume 37, pp. 215-216. https://doi.org/10.1038/s41587-019-0043-0

[63] Neil Stephens, 2018. Bringing cultured meat to market: Technical, socio-political, and regulatory challenges in cellular agriculture. Trends in Food Science & Technology, volume 78, pp. 155-166. https://doi.org/10.1016/j.tifs.2018.04.010

particularly in rural areas.

The crucial thing now is to plan ahead and prepare scaleable state-led support to help farmers transition. Paying farmers to be stewards of nature restoration (as was done with remarkable success in Costa Rica[64]) should be a major priority. If such payments are tied to carbon sequestration, these should be supported with a substantial carbon price, as recommended in our upcoming RePlanet report. Retirement payments for farmers wishing to exit the industry, state buyouts of farms, rural development funds for farmers seeking to start new businesses and tailored retraining programmes could all be part of the mix of achieving a just transition.

Throughout all policymaking, a useful maxim has been proposed by the think tank RethinkX: 'Protect people, not companies or legacy industries'. It is important to note that animal farming and its products are so deeply intertwined with European culture and history that decision makers should also consider ways in which the food revolution can be best narrativised in public discourse. We need to actively promote new positive stories of a post-reboot society, whilst also being patient and respectful about the speed at which such deep-set cultural ideologies can change and the stresses that will bring.

The death spiral: why the food revolution demands action now

Technological disruption is one of the greatest and most inevitable forces in history. At the dawn of the automobile in the early 20th century, breeding better and faster horses was clearly a futile pursuit. Within a short few decades it was game over for what had been humanity's main form of transport for millennia.

Many predict a similarly rapid collapse of livestock farming today. Think tank RethinkX, in their seminal report "Rethinking Food and Agriculture", describe how disruption caused by new proteins will send livestock into a vicious cycle of falling demand and rising prices:

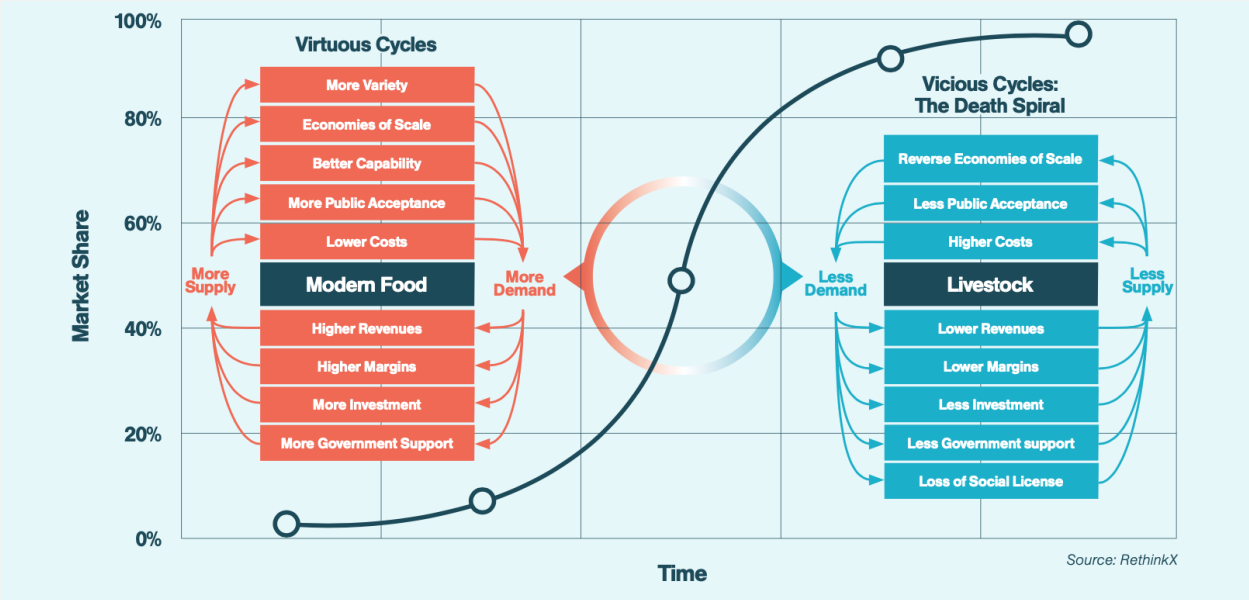
> "As demand for animal products is chipped away by modern alternatives, we will see the industrial system of meat production coming under ever-increasing pressure.
>
> Milk, hides (for leather), collagen, gelatin, and ground and tissue meat will be replaced by lower cost, higher quality modern substitutes. At a certain tipping point – we estimate at 10%-15% of the market – the incumbent industry will enter a vicious cycle. As the various cow product markets begin to be disrupted, prices of the remaining

[64] https://www.frontiersin.org/articles/10.3389/fenvs.2020.580724/full

products will jump as the full costs of production and processing will need to be borne by an ever-smaller number of products that still have markets available to them.

This price spiral and continuing reduction in demand will ultimately lead to the value chain breaking down as abattoirs, renderers, processors, and packagers see decreasing utilization and hence reversing economies of scale. Eventually, they will be forced to shut down as their economics continue to deteriorate. The beef and, especially, dairy industries operate on extremely thin margins, with high operating and financial leverage, and are propped up by government subsidies. Both are already hanging in the balance and just a small drop in demand will send them spiralling towards bankruptcy. While continued government support is certainly possible, the bill will continue to rise and is not sustainable in the long run. [...] This means that the disruption of the cow will be irreversible well before the new technologies are capable of producing the perfect steak at a competitive cost."[65]

Such potentially massive disruptive change for the livestock industry leaves governments with two choices: either continue to pour taxpayers' money into propping up a failing industry, or take immediate and progressive measures to harness the economic, environmental and social promises of the food revolution that can protect today's workers.



from RethinkX *Rethinking Food and Agriculture* (2019)

[65] https://www.rethinkx.com/food-and-agriculture-executive-summary

What governments must do to Reboot Food

Despite the incredible promise of this new revolution, powerful interests are stacked against it. Billions of dollars invested in the industrial animal agriculture sector, and a deeply embedded cultural romanticisation of even the most destructive agricultural practices, are putting the future of today's food revolution at risk.

Today, the market for food is strongly rigged against the transformation that our planet so desperately needs. Each year, $540bn is spent globally on agricultural subsidies, the majority of which goes towards supporting the otherwise uneconomic farming of animals[66]. According to the UN, 87% of this half a trillion dollars actively harms the planet[67]. As depressing as this sounds, repurposing this money also represents an enormous opportunity to transform our food systems for the benefit of our living systems and the next generation.

However, even beyond care for our environment and for future generations, failing to embrace the food revolution carries enormous economic risks for governments. Countries that commit significant public investment for precision fermentation have an opportunity to lead the pack and develop strong export markets. Meanwhile, countries that continue to prop up the declining and heavily subsidised livestock industry will leave farmers and their suppliers exposed to collapsing profits, stranded assets and eventual bankruptcy.

So, whether for the planet or for the economy, governments have a responsibility to act. Here's the policies they should put in place:

1. **Invest 2.5% of GDP over 10 years into rebooting our food systems**
    - Match the ambition shown by Kennedy's moonshot programme and invest 2.5% of GDP over 10 years into a rapid transformation of our food systems.

2. **Stop subsidies for animal agriculture, pay farmers a land-based subsidy to rewild instead**
    - Make animal farming and fishing ineligible for subsidies and end basic payments based on hectare-by-hectare use which have incentivised large-scale agricultural sprawl. Pay farmers and land managers for public goods and ecosystem services. Only some very low-yield forms of livestock grazing should continue to be eligible for rewilding and nature restoration subsidies, where the main aim is habitat restoration and food production is a by-product.

[66] https://www.fao.org/documents/card/en/c/cb6562en
[67] https://www.fao.org/documents/card/en/c/cb6562en

3. **Bring agriculture into the EU Emissions Trading Scheme (ETS) so emissions are capped and costed**
    - Despite being one of the biggest emitters of greenhouse gases, the agricultural sector is given a free pass to pollute. By bringing agriculture fully into the Emissions Trading Scheme, farmers would be forced to compete for increasingly scarce carbon credits to pollute whilst being paid for schemes such as rewilding that sequester carbon. The specifics are covered in a parallel RePlanet report.

4. **Subsidise plant-based food at the point of sale to encourage scale-up**
    - Reduce all taxes on plant-based foods to zero and then subsidise their cost at the point of sale to make them widely affordable as they achieve mass market. Subsidising at the point of sale guarantees a good price for producers and will help the poorest households directly.

5. **Implement a just transition for farmers and fishing communities**
    - A range of policies needs to be urgently considered, including: retirement payments for farmers wishing to exit the industry, state buyouts of farms, rural development funds for farmers seeking to start new businesses and tailored retraining programmes for rural workers.

6. **Set land use reduction and rewilding targets, suspend organic targets until yields match those of conventional agriculture**
    - Suspend organic farming targets until agroecology can reliably deliver yields comparable to those of conventional agriculture. The extra land demand of organic farming (i.e. agricultural sprawl), whose yields are typically much lower than those of conventional farming, counteracts any environmental advantages of lower inputs. Set binding environmental targets for reducing our agricultural footprint and ensure that spared land is rewilded.

7. **Limit patents on food innovation to 10 years**
    - There must be a balance between incentivising private sector innovation in crop and microorganism breeding, and the need for innovations to be widely shared. Limiting patents on food innovations to 10 years (as compared to 20 years for pharmaceutical patents) will allow the world, not just big agribusinesses and billionaire investors, to benefit from the breakthroughs. In addition, innovations developed in the public sector (e.g. universities) should continue to be publicly owned, not hived off to private companies.

8. **Legalise gene editing, genetic modification and other biotech breeding techniques**
    - New breeding technologies – such as the genetic editing of yeast and plants using Crispr – are essential to the new food revolution. However, in the EU, all are banned due to the political legacy of the 1990s-era anti-GMO campaign. All prohibitionary unscientific regulations on new food technologies should now be removed as they are harming both the environment and animal rights.

9. **Make sustainability labelling mandatory**
    - Make sustainability labelling – including land use and greenhouse gas emissions – mandatory so people can make informed decisions about how damaging their food really is.

10. **Ban advertising of land- and carbon-intensive animal-based foods**
    - Many countries have successfully reduced smoking rates through a ban on tobacco advertising. A gradually phased ban on advertising animal products is a simple intervention that would help support a cultural shift towards a rebooted food system.

What NGOs and charities must do to Reboot Food

Today, the vast majority of environmental charities are hindering, not helping, the food revolution. The most absurd and perplexing example of this is Friends of the Earth US's attempt to block the Impossible Burger from reaching the market[68] on the unscientific but emotive basis that it contains a genetically engineered component.

But the problems caused by the mainstream NGO community are more insidious than just such attempts to block game-changing environmental solutions. Most environmental campaign groups today support a 'less and better' approach to meat and dairy, which involves reductions in consumption while improving the 'quality' of remaining livestock production. This approach is exemplified by the Eating Better Alliance of 60 major NGOs which calls for a 50% reduction in meat and dairy and makes a series of suggestions for how to make the remaining meat and dairy we eat lower yield.

Such an approach is problematic on many levels. First, by seeking to turn animal protein into a more expensive luxury niche commodity, it is blind to questions of social justice and equality. Secondly, it promotes low-yield forms of farming that, by virtue of requiring more land, leave less space for nature and worsen our biodiversity crisis and the climate emergency. Thirdly, it sets up a dichotomy between input-efficient intensive factory farming

[68] https://www.bloomberg.com/news/articles/2019-08-28/impossible-s-grocery-rollout-gets-environmental-group-objection#xj4y7vzkg

and extensive livestock grazing when the latter – while clearly somewhat less appalling for the animals – remains the single most destructive farming practice in terms of land use and greenhouse gas emissions. Such an approach is anyway morally incoherent: either animal farming is something we want to phase out, or it isn't. Any mass exploitation or killing of animals is morally problematic when not strictly necessary.

What we're asking environmental NGOs to do:

1. **Campaign unambiguously for a plant-based future**
- It is past time to stop lending credence to the most destructive industry in history by romanticising low-yield forms of animal agriculture (e.g. 'grass-fed organic' beef). The 'less and better' approach is too unambitious for the crisis we find ourselves in and helps greenwash the immense damage caused by extensive grazing livestock systems.

2. **Support precision fermentation and educate your membership on its importance**
- Precision fermentation is the most promising environmental technology we have at our disposal, and yet most NGOs are silent on the topic or actively oppose it.

3. **Stop campaigning against biotech**
- Campaigning against genetic engineering and modification is a legacy of the 1990s, and needs to be consigned to the past. Today the scientific consensus is crystal clear: biotech breeding techniques can have enormous benefits in climate resilience, chemical use reduction and land use efficiency, and carry no more risks than conventional breeding techniques.

4. **Make land sparing a central priority of your work**
- Plastics, air pollution, carbon emissions... green NGOs have done a great job in recent years in raising awareness of such crucial issues, but they've neglected the single most important metric of environmental health: land use. Without radically shrinking our land use footprint, we have no hope of tackling the climate and biodiversity crises.

Conclusion

There has never been a better time to Reboot Food. Whilst in the past, ending industrial animal agriculture has entailed asking people to give up animal products, often without acceptable replacements, in the future precision fermentation and genetics mean that delicious and nutritionally-dense foods currently obtained by exploiting animals can be replaced by microorganisms instead.

This transition will not happen by accident, however, and is not yet inevitable. Making the revolution unstoppable will entail a major shift in government funding and policy priorities. This report has outlined what we believe these need to be, and how activists, NGOs, voters and consumers can help make this better future a reality. ♦