Techno-optimism, behaviour change and planetary boundaries

Adair Turner

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The theme of this lecture series is sustainability and world today is clearly not on a sustainable path – either in respect to climate change or in relation to biodiversity and the natural environment

- Given current trends of greenhouse gas emissions and fossil fuel use, together with existing policy commitments, the world is likely to warm by as much as 3°C this century, with potentially catastrophic impact on human welfare. And global warming threatens to take us past tipping points beyond which it will accelerate and become irreversible for many centuries. The melting of the Arctic ice cap is dramatically reducing the reflective albedo effect which sends some of the sun's warmth back out the Earth's atmosphere. And the melting of the Arctic tundra threatens to release huge amounts of trapped methane :
- As for biodiversity and the natural environment, many of us I'm sure will have seen David Attenborough's striking and saddening film about the extraordinary loss of natural habitat and biodiversity which has occurred in his lifetime. A loss which feeds back into climate change, with deforestation both driving a huge one off release of carbon dioxide and reducing the capacity of the forest to absorb carbon dioxide in future

So it is clear that a radical change of action is required. In the energy industrial system , we must reduce CO2 and other green house gas emissions to around zero by mid century : and we must halt the destruction of the great tropical forests and other land or ocean ecosystems before it is too late.

The question is not what we need to do but how. And tonight I would like to compare two alternative answers, which reflect two different assessments of what is possible

- The first we might label **Techno-optimism** – the belief that technological progress will enable us to reach zero carbon emissions while continuing to enjoy our existing standards of living, and indeed while bringing all people across the world up to the living standards which rich countries currently enjoy. So that we can continue to drive our cars, fly off on holiday , and eat big steaks as long as the cars are electric, the planes are use biofuels, and the steaks are made from synthetic meat .

- The second philosophy we might label the **End of Consumerism**, which argues that current rich country living standards are inherently unsustainable whatever the pace of techno logical progress, and that our demands for energy and materials are taking and will continue to take us far beyond sustainable planetary boundaries even if an increasing share of electricity comes from renewable sources. So that if we care about sustainability we have to get on our bicycles, stop flying and give up red meat.

Of course like any binary choice this one oversimplifies. Many sensible people rightly support a balanced mix of both approaches and philosophies. And there are crucial dimensions – such as how to build a circular economy of relentless recycling of materials – which sit somewhat orthogonal to the choice I am highlighting here.

But I think this choice does capture a key dimensions debate about how to fix our sustainability problem – the difference as it were between the business elite, and Extinction Rebellion, between Elon Musk and Greta Thunberg.

So in my lecture this evening, I want to explore the relative merits of these different approaches. And I will suggest that there is a very major difference between the long-term and short-term and between different areas of the economy and different forms of planetary boundaries.

- Controversially perhaps I will suggest that across many economic activities and forms of consumption, there are in the long term almost no relevant planetary boundaries – with no limit to how much green electricity we can sustainably produce and consume , and therefore no **long term** limits to how much we can heat or cool our homes , drive our electric cars or fly[1]
- But conversely that there are severe and immediate planetary boundaries in other sectors of the economy, and in particular in relation to food and textile production, which may require dramatic behavioural change, and in particular diet change, if we are to avoid disaster

In terms of science, the distinction can be summed up as follows

[1] In footnote 5 on page 7 I note that one possible caveat to this hypothesis , which arises from the "rebound effect", could suggest a revised precise form of the hypothesis, while preserving the strong distinction between the severity of planetary boundaries arising from different areas of human consumption

- In the arena of physics and inorganic chemistry, and the use of photons, electrons and ions to provide us with Work and Heat (or Cool) , and the minerals which make possible their effective manipulation, human kind faces no relevant long term planetary limits to our ability to produce and use as much zero carbon energy as we could possibly want
- But in the arena of organic chemistry and biology, of everything to do with life on earth, of photosynthesis and the production of complex hydrocarbon, carbohydrate and protein molecules, and the implications for land use, we must recognise inherent planetary boundaries which we are already going far beyond .

And that distinction has, I will argue, important implications for policy.

Cheap green energy : photons, electrons and ions

Energy production and consumption – in our industrial and transport systems , our offices and homes – today account for the majority of all green house gas emission – about 30Gt per annum . That's because 80% of our primary energy comes from fossil fuels, the stored product of photosynthesis over millions of years which we are releasing and burning in just a few hundred years .

But the good news is that we know how to decarbonise all of this. And in the long term – indeed even within just 30 -40 years, we can achieve a world of close to limitless, and cheap zero carbon energy. So cheap and limitless indeed, that in the second half of the twentieth century a focus on improving end use energy efficiency may become largely irrelevant.

Ten years ago when I was the first chair of the U.K.'s climate change committee,, this future was not so clearly visible. But over the last 10 years the cost of solar and wind has collapsed far more dramatically than most of us dared hope – onshore wind costs down over 60%, solar over 80%, and offshore wind costs also now falling rapidly.

When Germany first subsidised the installation of solar PV in the mid y 2000s, it was paying German farmers over 40 euro cents per kilowatt-hour to put panels on their roofs. A recent power auction in Portugal produced a price of 1.1 eurocents per kilowatt-hour – that's a fall of 97%.

And these falls are bound to continue, A recent report entitled "Solar's future is insanely cheap" – suggests that by 2050 solar electricity could cost less than 1.5c per kwh even in the less sunny locations , and below 0.5 cents per kilowatt-hour in the most favourable locations[2]. This may be towards the more optimistic end of expectations – but even in more conservative analysis big picture is still very clear - renewable electricity generation will in future be significantly cheaper than fossil fuel-based electricity today.

The crucial question indeed is no longer the cost of generation , but what to do when the sun doesn't shine and the wind doesn't blow – how to balance supply and demand across the minutes, hours,days and weeks in a system dominated by intermittent renewables. But here too, improving technology and declining costs provide the answer.

Lithium ion battery costs have collapsed 85% in the last 10 years and will keep on falling, providing an increasingly cost-effective way to balance supply and demand over the diurnal cycle. Multiple technologies could play a role over longer durations, including pumped hydro storage, compressed air, liquid air, and flow batteries. And the cost of producing hydrogen from electrolysis of water is on the verge of the sort of collapse we saw in solar and batteries, making it economic to turn surplus electricity into hydrogen, and then burn that hydrogen in gas turbines to produce electricity when needed.

As a result, we can now plan with certainty to build zero carbon electricity systems whose total cost of operation – including all the storage and flexibility needed – will be at least as low as existing fossil fuel systems – and in favourable locations significantly lower.

With cheap zero carbon electricity, we should electrify as much of the economy as possible – and as a result automatically achieve a big improvement in energy efficiency.

- A typical internal combustion engine passenger car turns only about 25% of the chemical energy in petrol into kinetic energy to drive the car forward – the rest is wasted as heat. An electric engine by contrast will turn 90% of the battery energy into kinetic energy and less than 10% into wasted heat.
- Similarly in residential heating, an electric heat pump is 3 to 4 times more efficient at turning energy input into heat within the home than even the most efficient gas boiler.

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[2] Solar's Future is Insanely Cheap (2020) – Ramez Naam

While even in the so-called hard to abate sectors of the economy – such as steel and cement, shipping or aviation, decarbonisation is technologically and economically possible by 2050 ,and while here carbon capture and storage and bioenergy will play some role, in the long term the key technologies here too will be electricity, hydrogen and hydrogen derivatives

Steel can be produced using hydrogen as the reduction agent not coking coal. Ammonia, made from the sysnthesis of hydrogen and nitrogen, can be burnt to power zero carbon ship engines. For a transition period, biofuels will probably be used to power aircraft but in the long term synthetic fuels made out of hydrogen and carbon dioxide from direct air capture, are likely to power guilt free flight.

As for plastics , whose production at present relies on fossil fuel feedstocks, and which at end of life often result in soil or ocean pollution, with cheap enough electricity we could recycle all plastics, whether via the mechanical remelting and remoulding of the major polymer types, or by chemical recycling , which breaks the polymers down into their constituent molecules and atoms, and then recreates the plastic from scratch.

With enough electricity, we can decarbonise almost all of our economy. True there are some exceptions – we may never , for instance be able to decarbonise cement production without capturing and storing the CO2 inevitably produced by the chemical reaction which starts by changing calcium carbonate ($CaC0_3$) to calcium oxide (CaO) plus CO_2

But the exceptions are at the margin : the big picture is that by the second half of the 21st-century we can electrify our way to a zero carbon world.

The Energy Transition's Commission (ETC) scenario for 2050 therefore describes a world in which global electricity use increases from today's 27,000 TWH to as much as 100,000 TWH, with electricity then accounting for about 65% of total final energy demand versus 20% today, and with hydrogen and hydrogen derivatives potentially accounting for another 15%[3].

The trivial impact on living standards

[3] Making Mission Possible: Delivering a Net-Zero Economy (energy-transitions.org)

Such a world is certainly technologically possible – and once we have achieved it, the cost to living standards , even if measured in conventional GDP terms, will be at most trivial and quite possibly less than nil.

- In some sectors, such as road transport, green electrification is going to make people richer, even quite separate from the beneficial climate effects, because EVs will be cheaper than ICEs both to buy up front and to run. If we're not careful that could actually make congestion problems worse, but its impact on conventionally measured living standards will undoubtedly be a positive.
- In some sectors, such as shipping or steel, intermediate costs may increase significantly – with a tonne of steel say 25% more expensive or freight rates up 50% or more, but when you work out what that implies for end consumer prices the net effect will be trivial
- And in some specific sectors, such as aviation, decarbonisation will probably require somewhat higher consumer prices, but with the impact on consumer budgets offset by savings apply

So that across all sectors, the impact will be no more than a 1% reduction in conventionally measured living standards in 2050, falling thereafter and probably at some time becoming negative, as green electricity gets relentlessly cheaper

Limitless green energy

Not only is green electricity going to be cheap – it is also essentially limitless.

For many decades, some scientists have dreamt that nuclear fusion will be able to deliver limitless, zero carbon, safe, cheap electricity. And I don't exclude the possibility that nuclear fusion on earth may be part of our limitless green energy future.

But the wonderful reality is that human beings already enjoy the benefit of limitless energy delivered from an unbelievably massive nuclear fusion plant fortuitously placed at a safe 92 million miles away from Earth – the sun

Each day the sun shines down on earth 8000 times as much energy as all human uses and we only need to capture and use 1/80 of 1% of that energy to have a completely decarbonised energy system.

And if we produced **all o**f the 100,000 TW hours of electricity in the ETC's 2050 scenario from solar PV, the panels would only need to cover about 1% of the global land area, and about 0.3% of the global surface area if we could also use some of the surface of the oceans.

In fact it would never make sense to rely only on solar PV – an optimal renewable system would use a mix of renewable forces – solar, wind and hydro. But some of these resources too are abundantly available. The International Energy Agency estimates that the total technical potential for offshore wind is as much as 420,000 TW hours, which is at least 10 times what will need as an optimal offshore wind element within our future electricity system.[4]

Now of course solar and wind developments may have environmental local environmental and aesthetic impacts which we will need to manage. And local land availability may be a constraint in specific densely populated nations : China could easily meet mid century electricity demand of 15000twh (twice current levels) while devoting only a trivial % of its large lightly populated western provinces to solar PV : if Bangladesh , with a population density 8 times higher, had the same electricity demand per capita, and attempted to meet it all with solar PV , the land use requirement would be over 15% of the total land area in a country where almost all land is already intensively used.

Our future global zero carbon energy system will therefore need to involve a new zero carbon form of international energy trade , whether in the form of High Voltage electricity transmission , or of hydrogen or ammonia.

But there are no **planetary** limits here, and no unsustainability. No danger that by developing a green electricity system capable of producing 100,000 TW hours per annum, or even much more, we degrade the capacity of the eco system to support human welfare in future. [5]

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[4] See IEA World Energy Outlook 2019 , Chapter 14

[5] The one caveat that could challenge this techno-optimism relates to the widely observed " rebound effect" , in which , if energy , or any other intermediate input , product or service gets cheaper , human beings simply use more of it e.g. over the last 30 years , the auto industry has made great strides in improving technical efficiency , as measured by the energy input needed to move a given weight of auto , but a large share of this improvement has been offset by increases in the average size and weight of autos . There may therefore be a danger that as green energy gets cheaper and ever more abundant , humanity uses so much of it that it reaches new planetary boundaries (eg a lack of land for solar PV panels). Thus while it is clear that humanity could sustainably take total global electricity generation from today's 27000twh per annum to 100,000 twh , if rebound / price elasticity effects then led to 1million twh of electricity demand , the story would change. And there are some worrying signs that humanity is indeed capable of devoting enormous amounts of energy to activities of no ultimate value for human welfare , such as bitcoin mining.   more precise version of the central

Plentiful minerals

But what about all the minerals needed to build this huge zero carbon energy system ?

- The cobalt, magnesium, nickel and lithium for batteries
- The silicon for solar panels
- Rare earths such as neodymium and dysprosium used in magnets for electric motors
- Or copper for use in electrical transmission and distribution systems

Won't mining these impose terrible environmental harm, and take us beyond planetary boundaries in a world of scarce supply ?

And what about the 7200m tonnes of water which would be needed to produce 800 m tonnes of hydrogen in a world already facing significant water constraints ?

Well, the answer is , when you do the detailed analysis, that there are no inherent scarcities of supply for any of these materials, and water consumption for electrolysis is completely manageable and very small compared with the big water user – agriculture.

And while mining for these could impose local environmental impacts which need careful management, they are far far smaller than the environmental impacts imposed by the existing fossil fuel-based system

Consider for instance the supply of lithium.

Lithium is a crucial element in batteries. And if in 2050 there are 2 billion cars on the road each with a 60 kWh lithium ion battery that means 120 TW hours of battery capacity, which in turn implies something like 19m tons of lithium inside those batteries.

And even if we get really good, as we must, at recycling end-of-life batteries, there will always be some new lithium input needed, and a significant need for lithium mining as we build up the stock of batteries to the required level. At peak that might imply mining about 1 million tonnes of pure lithium per

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thesis of this lecture would therefore become not that planetary limits to the production of zero carbon energy are completely non -existent and permanent but that for foreseeable future they are massively less important than those which relate to our current production of food and materials annum. And lithium mining if done badly can have significant adverse local environmental impacts – with toxic chemicals such as hydrochloric acid used in extraction from rock deposits , and large water inputs used to extract it from salt flats.

But there is no shortage of available lithium supply – lithium indeed is one of the most abundant materials in both land and oceans – and economically accessible resources of lithium are currently estimated by the US Geological Survey at 80 million tonnes , an estimate up from 53m tonnes in 2018 , reflecting a familiar pattern in which once a mineral becomes more valuable , more resources are identified.

And the environmental impact of mining 1 million tonnes of lithium per annum is bound to be minimal compared with the local environmental impact, let alone the global climate impact, of mining 7000 million tonnes of coal per annum.

And that indeed is the pattern across all the material inputs we need for our green electric system – their adverse environmental impact is an order of magnitude, or two or three orders of magnitude, smaller than our old fossil fuel based system .

An essentially renewable system

Which is not just a happy accident, but inherent to the very nature of the renewable system which we are building.

We often use that word “renewable” but fail to reflect on how fundamentally different this system is from one based on fossil fuels.

Until now, to get energy , we have had to take massive amounts of fossil fuels out of the earth each year – 7000 million tonnes of coal, 36.5bn barrels of oil, 3.9tr cubic metres of gas - and burn it in chemical reactions which produce 30 billion tonnes of CO_2. And then the next year, we have to do the same all over again.

In a renewable system by contrast, we take much smaller quantities of inorganic minerals and we put them into structures – silicon in the solar panels, copper in the wires, lithium in the batteries, rare earths in the motors. The photons of sunlight and the motion of the wind, then generate streams of electrons which we can use to heat or cool buildings, drive our machines, or create hydrogen molecules, - all of which happens silently, and with almost no local pollution, let alone global atmospheric pollution.

And at the end of the year those structures are largely unchanged, and already in place to do the same job all over again.

Of course it's not quite like that, because some atomic and molecular structures undergo complex microscopic change and degradation – batteries for instance slowly losing capacity as the result of the build of crystal/ salt formations.

Which means that we need to repair, replace and recycle, with some new mineral flow required , to keep the system going.

But the difference with the fossil fuel system is still fundamental. This future system is <u>essentially</u> a renewable system, and for that reason faces no long-term planetary boundaries at a scale relevant to human energy demand.

But we still face potential disaster

So that if our focus was solely on where we could be in the second half of this century, and solely on our industrial, transport and building heating and cooling systems ; on whether we could by then fly without guilt ; and whether it will be sustainable for the poor of the tropics to use air-conditioning as freely as we in the high latitudes use winter heating – then the Techno-optimists seem to win hands down .

But today we are still on a path to climate disaster and we are destroying the natural environment in an unsustainable and potentially irreversible fashion. That is for two reasons :

- First because we have left it dangerously late to move away from our fossil fuel based energy system
- The second because in our use of land and oceans for food, textile and other organic material production, we are already exceeding planetary boundaries – and, unlike in the energy and industrial systems, do not yet have a clear vision of how to draw back from them.

Dangerously late

The first problem is one of timing. If 40 years ago, responding to early scientific understanding of the global warming threat, we had set out forcefully to build our technically possible renewable system, we could have done so in good time without the need for major changes in most aspects of consumer behaviour.

But we didn't. We allowed the stock of CO_2 in the atmosphere to keep rising, and if we are now to have any hope of limiting global warming to non-catastrophic levels, we must not only achieve zero emissions by around mid century, but reduce emissions by something like 50% in the next decade.

And the latter is much more difficult than the former. Given 30 years and determined policy, we can change our capital stock to support zero carbon production almost entirely and at a very low economic cost – steel production can be zero carbon in 2050, so can shipping, so can long-distance trucking.

But it's much more difficult to achieve a 50% reductions via changes on the supply side of the economy within just 10 years, because much of the capital stock we will use in 10 years time is already in place.

And that means that changes in lifestyle and consumer behaviour may be essential to achieve emission reductions over the next 10 years, even if they will be unnecessary once we get to the zero carbon renewable economy of 2050 and beyond.

A fundamental problem – inefficient photosynthesis

The second problem is more fundamental, because it derives from the inherent inefficiencies of the photosynthetic process, and our current means of animal protein production.

Human beings use each year about 450EJ, which is 125,000 TWH, of non-food energy. In addition if 9 billion people in 2050 each enjoyed an adequate calorific intake of say 2200 calories per day, that would mean 7400 TWH of energy intake in the form of food . So that required food energy input is only about 6% of total human non food energy use. the non food total.

But unlike our energy for heating/ cooling and machinery operation , we cannot substitute electrons for carbon-based molecules in the food we eat.

Instead we have to derive food from photosynthesis of vegetable matter, and that's a far less efficient way of converting solar energy into usable energy than when we convert photons into electrons in a solar panel. Research by Tim Searchinger and others for the World Resources Institute shows that even fast-growing sugarcane on highly fertile land in the tropics converts only around 0.5% of solar radiation into sugar, while for maize grown in Iowa the solar to biomass-energy conversion efficiency is a still lower 0.3% . BY contrast, a field of solar PV panels might achieve an average % yield of 15% , and this figure is slowly increasing over time with technological advance. [6]

Inevitably therefore photosynthesis to produce food requires large amounts of land, even though energy in food is only about 6% of our total energy requirements. And while we can improve the efficiency of the photosynthetic process by applying nitrogen fertiliser, that in itself has a significant climate change effect, via the production of nitrous oxide. In addition food production via photosynthesis in fields requires large water inputs ; of total global fresh water demands of 4 trillion m^3 (which is also of course 4 trillion tonnes) over 70%, i.e. around 3 trillion tonnes, is accounted for by agriculture – which makes the figure I quoted earlier of 7 billion tonnes for future hydrogen electrolysis, little more than a drop in the ocean .
(https://www.worldbank.org/en/topic/water-in-agriculture
https://ourworldindata.org/water-use-stress)

Moreover and crucially, if we choose to consume food in the form of animal protein, we essentially take the vegetable product of photosynthesis and put it through some very inefficient processing machines called animals, some of which, in particular cattle and sheep, produce methane gas as a byproduct.

As a result agriculture in total is currently responsible for about 11 GT of greenhouse gas emissions, only about 0.7 of which reflects the energy used in agricultural processes, with about 4GT of CO_2 equivalent emission resulting from methane release, 1.5 gigatons from Nitrous oxide, and about 5 GT from the land-use changes which are primarily driven by agriculture, and above all by meat production[7].

So that even if we could reduce energy system emissions by 50% by 2030, and to zero in 2050 , we would still be threatened by harmful climate change. And still destroying natural habitats and biodiversity in an utterly unsustainable fashion, and in a way which threatens to become self reinforcing and irreversible, as for instance the deforestation of the Amazon induces climate and local weather effects which lead to yet faster deforestation.

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[6] Avoiding Bioenergy Competition for Food Crops and Land | World Resources Institute (wri.org)

[7] See Making-Mission-Possible-Full-Report.pdf (energy-transitions.org), Box A, Page 30, for a breakdown of agriculture and land use emssions

Here therefore in the agricultural system as currently organised, we do face and have clearly gone far beyond planetary boundaries, and we need a strategy for drawing back.

That strategy could entail a mix of three elements;

- The first is non-radical change in food production technologies and systems . These could play a significant but still only partial role. New forms of animal feed may be able to reduce methane emissions at least to some degree. Nitrogen fertiliser could be used more efficiently, and a nitrogen tax would help create incentives to do so. And perhaps most important, better incentives could encourage more effective land use even with largely unchanged technologies. It's a striking fact that total global land use for agriculture is not actually increasing, but harmful land-use change still occurs because we are simultaneously destroying natural habitats to create new agricultural land, and abandoning existing agricultural land , which has been degraded by harmful practices, or which is simply more expensive to use than taking new land out of nature, given multiple perverse subsidies and incentives.
- The second way forward is diet change, encouraging people, nudging them, persuading them or incentivising them via methane taxes, to reduce their consumption of red meat and dairy. Such diet change has been urged both by the recent Eat Lancet report[8], or by WWF's report on *Eating for 2 degrees*[9] , which shows that a major change in UK diets , including in particular a more than 50% reduction in red meat consumption, could reduce the U.K.'s carbon footprint from food consumption by 30% even without a change in technology.
- The third way forward is radical changes in the technology of food production. This could include vertical controlled environment farming to produce green vegetables with 90% less water and 99% less land than conventional horticulture : breeding insects as feedstock for fish production or as direct human food :, synthetic production of carbohydrates such as being developed by Solar Foods Finland. And it could include synthetic meat protein production, using Precision Fermentation and energy inputs to produce meat equivalents while

[8] Food in the Anthropocene: the EAT–<i>Lancet</i> Commission on healthy diets from sustainable food systems (thelancet.com)
[9] https://www.wwf.org.uk/eatingfor2degrees

using 100 times less land, and one tenth 10th as much water, as those inefficient animal processing units called cows.

Such a shift would make food production like non-food energy production – an input to human welfare and consumption where planetary boundary limits to sustainability are largely non-existent, since the only inputs to this type of food production are :

- Knowledge – which is limitless
- And electricity, which during this century will become abundant, cheap and zero carbon

In the long run it seems certain that these radically new food production technologies will play a major role.

As recent report by the Rethink X think tank sets out[10], the technology of precision fermentation improves every year while the traditional technology of the Cow is as inefficient this year as it was the last. And If you have one technology relentlessly improving, and another staying still, it is simply a matter of time before the new technology beats the old.

But that takes us back to the issue of timing – that we have technologies which will make planetary boundaries close to irrelevant by the late 21st-century, but we still face an ecological disaster today.

[10] https://www.rethinkx.com/food-and-agriculture

Four implications for action

What then are the implications for action – whether by governments , companies or individuals ? Let me suggest 4 **:**

First we must build the future zero carbon electricity system as fast as possible, decarbonising electricity production and electrifying as much off the economy as possible – and telling people the exciting story about our future world of abundant cheap zero carbon energy – because if we make the climate change story a**lway**s about constraints, impending disaster and the need to consume less, we will probably lose a lot of people.

Second we must get emissions down fast over the next 10 years, and we must therefore persuade as many people as possible to make responsible consumption choices today even if those choices will be unimportant in 50 years time. Cutting down or cutting out red meat and dairy, travelling by train not plane wherever possible, bicycling and using public transport as much as possible rather than by car, avoiding unnecessary purchases of multiple clothes worn only a few times – all of that must be part of the story, motivating as many people as possible to make lifestyle changes, and to discover, as they undoubtedly will ,that once they have made make them, it is no sacrifice at all.

Third we should drive as fast as possible the radical new technologies of food production, aiming to make food, like non-food energy, an environment where in the long term no relevant planetary boundaries need exist.

And finally we must motivate as rapidly as possible – from governments, from companies and from individuals - the big flows of finance which can support eco-system restoration, reforestation, and better, less destructive land-use practices, aware that we are running out of time, both to prevent climate change and to avert an irretrievable loss of the biodiversity and the beauty of the natural world .