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A NEW WORLD OF ENERGY

From scarcity to abundance

by Stefan Breit, Venkatesh Rao and Detlef Gürtler

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Preface

"The future always comes too fast and in the wrong order." US futurologist Alvin Toffler's sober assessment probably speaks to many energy companies at the moment. They are being confronted with fundamental changes to markets and technologies whose consequences can already be felt today and will lead to an entirely new energy landscape.

These changes will not wait for us, and they will not conform to any legally stipulated order or logic. New technologies and business models will emerge simultaneously or one after another, complementing or excluding each other, proving themselves against the competition or disappearing again. The future of energy cannot be sorted. But it can be steered.

For this to succeed, however, we need to actively engage with the future, anticipate potential technological leaps, seize opportunities and ward off risks early – or be paralysed by them. Our main goal is still to guarantee a secure, affordable and environmentally friendly energy supply for everyone.

We want to shape the new world of energy, not wait for it to shape us. Our generation has the privilege of participating in this task.

Benoît Revaz
Director, Swiss Federal Office of Energy

Summary

Over the course of the 21st century, the global energy system will transform from a system of scarcity to one of abundance. Not only will sufficient energy be available whenever and wherever it is needed, it will also come entirely from non-fossil sources. The old industrial world of oil will be succeeded by the new digital world of electricity.

A combination of forces will make this possible: technological progress, of course, but also economical, ecological and political developments. This fundamental transformation of the energy system also entails a fundamental transformation of global society. It will culminate in a post-carbon society that enjoys an abundance of energy, based on radically different social, political, economical and cultural parameters.

We cannot predict the exact shape of this brave new world of energy. No crystal ball will tell us. Negotiation of its complexities will be up to the transitional society living between today's scarcity and the abundance of the future. Just as the energy system progresses along a string of transitional technologies, a transitional society will also establish itself. It will experience, advance and ultimately facilitate the metamorphosis.

This will not happen from one day to the next, nor will it be smooth or subtle. It will involve steps, jumps and breaks that will affect everyone involved. Each development will be a shift, changing the way in which we produce and consume energy. Management of this energy system will take more than determination and control of the conditions in which it will operate. It will require preparation for potential errors and a planned response to positive and negative events. This study collected 30 of today's most important developments in terms of social, technological, economical, ecological and political change in a "trend landscape", and analysed how they could shape the energy system of tomorrow.

State institutions will play a leading role in our transition to an energy-abundant society. Why? First, states become more important in an electrified world: they control power grids almost everywhere. Second, investment in a society of abundance will prioritise economic benefit over economic gain. Finally, our development to an overly affluent society will occur mainly through crises and upheaval. The state is usually our go-to helper in such situations. Technical disruptions, social revolutions, environmental catastrophes: every shift in the energy industry, whether caused by man or nature, is an opportunity for action. It is a chance to future-proof our energy system.

The goal: from scarcity to abundance

Everything is energy

A warm home, a trip to Ticino, WhatsApp chats, family visits, Google searches, theatre plays, five-course dinners, coffee, gift wrap, hitch-hiking, running, smoke machines – energy is our constant, invisible companion.

Energy is so much more than a physical value measured in joules and kilowatt hours. It is more than firewood, petrol or water waiting behind a concrete wall to tumble down the mountain and power turbines. Energy is a fundamental part of the lives we live.[1] Energy is, in fact, so important that it accounts for 18% of global gross domestic product.[2]

Energy is a prerequisite for order and change alike. It must be used to reduce and create complexity. As a key element of every culture, energy is inevitably the central focus of any cultural change. Almost every new source of energy has rung in a new era for humanity.[3] Ancient Egypt owed its wealth to the hydropower of the Nile; the industrial revolution in the 18th century was a consequence of the newly invented steam engine and the development of coal as an energy source; the use of oil in combustion engines revolutionised transport in the 20th century. It is thanks to the constant discovery and use of new sources of energy that humanity has achieved what used to seem utopian: a level of material abundance that ensures our survival and protects us from hunger and cold.

In the 21st century, we will go one step further. The global energy system will change as radically as global culture. Today, energy ensures the survival of many. Tomorrow, it will ensure the survival of all. For the first time, a centuries-old system of scarcity will transform into a system of an energy-abundant society. This monumental change will not happen from one day to the next, nor will it be smooth or subtle. It will involve steps, jumps and breaks that will affect everyone involved. These shifts are the key element on our way to the future of energy, and management of them will be the main challenge for politics, the economy and society.

This endeavour will be our task for the coming century and makes the question of the future energy system one of the most important of today. Transformation of the energy system into a stable, sustainable system for the future will require measures of unprecedented complexity: political coordination, technological development, long-term economic sustainability and ecological compatibility – even though they cannot be planned precisely. This applies on a global as well as a national level, as national energy systems are networked and interwoven with international developments, from power grids to oil pipelines and the Paris climate accord of 2015.[4] This is why the scope of this study is not limited to Switzerland alone. Many developments in the energy sector take place on a global scale; others develop locally and spread globally.

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1 Garcia, Tristan (2017): Das intensive Leben: Eine moderne Obsession. Suhrkamp Verlag.

2 Schmidl, Johannes (2014): Energie und Utopie. Sonderzahl Verlag.

3 Hufendiek, Kai (2015): Energie: Entwicklung und Bedeutung. Institut für Energiewirtschaft, Universität Stuttgart. Online: http://www.ier.uni-stuttgart.de/lehre/skripte/esys1/datei/es1_k01_2010.pdf

4 United Nations (2015): The Paris Agreement. Online: http://unfccc.int/paris_agreement/items/9485.php

There is no doubt that in order to transform our energy system, we will need a lot of energy. Energy policy and management in the 21st century will have to respond to change, crises, traumatic events and disruption. This may involve prevention of these occurrences or preparation for them as thoroughly as possible – or, in some cases, even leveraging crises for otherwise unenforceable reforms. Even if individual shifts cannot be predicted accurately, physical and psychological preparation will allow us to make the most of them.

Transitioning to an energy-abundant society

Everything seems to be scarce in our current global energy system.[5] It depends on sources of energy that developed from the decomposed remains of animals and plants aeons ago. More than 85% of the energy we consume is generated from fossil fuels, such as coal, oil or gas.[6] We are consuming a past we cannot replace and raw materials that are thin on the ground in many places. Globally speaking, the raw material used for the production of energy is a scarce commodity. It is distributed unequally, it is unsustainable and ecologically destructive. It enforces a complex system of energy production and distribution dependencies, down to the local level. But this scarcity has an expiry date.

The energy system of the future will be radically different. In theory, energy has never been scarce and never will be. It is our ability to use it that has been limited. The sun, the mother of all energy sources, is available in virtually unlimited quantities: it emits as much energy to earth in one hour as the entire planet consumes in a whole year. Even Switzerland, with its comparatively low solar radiation and high energy consumption, receives 200 times more solar energy than it needs. Of course, this immense power source cannot be exploited in the short term, but it highlights the sheer potential that can be tapped by technological progress. The technologies that generate and store electricity, power and heat from renewable sources are currently developing at a pace that at some point this century will allow us to live in an energy-abundant society with no fossil fuels.[7]

At the moment, we have only a rudimentary idea of the shape this future system will take. We know that it will be decarbonised, electrified and digital, fuelled primarily by renewable energies. Its main driver might be the sun, nuclear fusion or a whole new source of energy we have not yet discovered. Energy production might be centralised or decentralised, and we do not know how the energy system will ultimately be organised.

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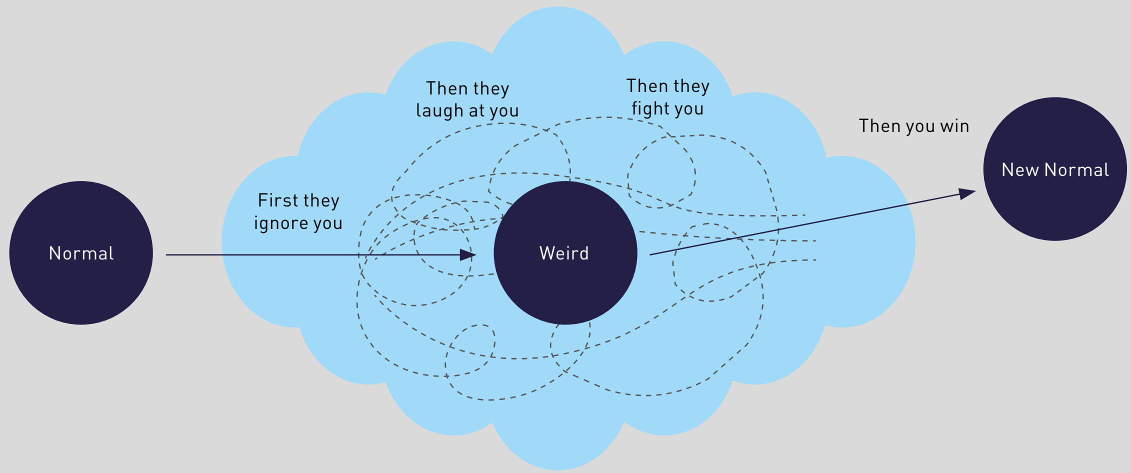
5 Sperling, Franziska & Schwinghammer, Alexander (2015): Ist Energie knapp? Kulturanthropologische Forschungsperspektiven im Bereich der Energopower und Energopolitics. In: Tuschek, Markus & Grewe, Maria (2015): Knappheit, Mangel, Überfluss. Kulturwissenschaftliche Positionen zum Umgang mit begrenzten Ressourcen. Campus Verlag GmbH.

6 Ritchie, Hannah & Roser, Max (2018): Energy Production and Changing Energy Sources. Online: https://ourworldindata.org/energy-production-and-changing-energy-sources

7 Diamandis, Peter (2017): Disrupting Energy. Online: http://www.diamandis.com/blog/disrupting-energy

Venkatesh Rao's development model of technical, economical and social progress



Source: Venkatesh Rao, www.breakingsmart.com

Some 600 years from now, decarbonisation will no longer be a choice, as the earth will quite simply run out of fossil fuels. The transition is not going to wait for that to happen. To quote Ahmed Zaki Yamani, the former Saudi Arabian Minister of Oil and Mineral Resources: "The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil." While the progressive thinkers among us head towards a future of energy that beckons with decentralisation, localisation, collaboration, peace and democracy, others cling to dated structures: oligopolies, centralisation, hierarchies and preservation of power.

A transitional phase stands between today and the future, between scarcity and abundance. Venkatesh Rao's progress model helps us to understand this phase.[8] It is applicable equally to technological, economical and social progress. The theory provides a consistent method of describing the point of departure ("normal") and conclusion ("new normal") of any aspect of progress. This long-term view detaches the development itself from the path it takes: "The most important technological advances, once recognised, will inevitably be exploited to their maximum potential."[9]

8 Rao, Venkatesh (2016): Breaking Smart. Prometheans and Pastoralists, https://breakingsmart.com/de/dont-panic/

9 Rao, Venkatesh (2016): Breaking Smart. Prometheans and Pastoralists, https://breakingsmart.com/de/dont-panic/

Do we consume more and more when faced with an abundance of supply, or do we simply stop once saturated?

In contrast, the duration and shape of the phase in between, which Rao calls "weird", cannot be predicted. He draws an analogy to a quote commonly attributed to Mahatma Gandhi: "First, they ignore you. Then they laugh at you. Then they fight you. Then you win." As the development progresses, it necessarily remains open – but the result is clear: "As long as there is untapped potential, individuals will compete with each other and adjust their strategies unpredictably until it is exhausted."[10] Even if it had been clear, for example, that a predominantly stationary use of the internet ("normal") would eventually develop into a predominantly mobile use ("new normal"), nobody could have predicted how this development would take shape. Who, in 1997, would have guessed that the computer manufacturer Apple, which had just narrowly escaped bankruptcy, would achieve a major breakthrough in the transition to mobile internet by stripping a mobile phone of its keys and asking users to slide their fingers over a glass panel?

The energy sector is particularly compatible with this model, as both "normal", the current state, and "new normal", the distant state, can well define the utopian-sounding end of development. To summarise both again:

NORMAL
Energy is scarce. Its production and distribution is expensive. Energy equals depletion. Its production from fossil fuels is unsustainable and ecologically destructive.
↓
NEW NORMAL
Energy is available at any time and anywhere in the required quantity. We meet 100% of our energy requirements from non-fossil fuels.

Technological and social transformation

The forces that will lead to this "new normal" do not spring from technological progress alone. Economic drivers, such as investment in new battery concepts, and environmental motives, such as those defined by the Paris climate accord, are also at play. Society also offers compelling incentives to move in the direction of

[10] Rao, Venkatesh (2016): Breaking Smart. Prometheans and Pastoralists, https://breakingsmart.com/de/dont-panic/

energy abundance: consumption is always sweeter than sacrifice. This transformation will culminate in a post-carbon society with radically changed social, political, economic and cultural parameters. Again, this cultural development can be summarised in terms of a "normal" and a "new normal":

NORMAL
Petroculture
↓
NEW NORMAL
Energy-abundant society

Petroculture has shaped our lives since the 1920s.[11] A group of researchers led by the Canadian cultural scholar Imre Szeman gives this definition: "We use this term to emphasise the ways in which global society is an oil society through and through. It is shaped by oil in a physical and material way, from the cars and motorways we use to the plastics that fill every space of our daily lives." They argue that this way of life impacts not only on our physical environment but also on our values, practices, habits, beliefs and feelings. "That's why the transition from fossil fuels to other energy sources will require more than new energy technologies. We will need to transform and change our cultural and social values at the same time."[12]

On account of this major cultural transformation, it is still difficult to predict in which form the "new normal", the energy-abundant society, will materialise. But it will materialise: the fundamental transformation of the global energy system will bring a transformation of global culture with it. It is tempting to envision a proverbial land of milk and honey, a paradise where energy flows freely like wine, and everyone receives their fair share of the feast. Rather than gingerbread houses, it will have houses that are producers of energy. And indeed the question of the commonality of energy and food arises. Do we consume more and more when faced with an abundance of supply, or do we simply stop once saturated? When it comes to food, the latter is true. In terms of energy consumption, there is no physical limit, so we have no biological reason to stop consuming energy in the face of abundance. But perhaps the future global affluent society looks quite different, as German storytellers dreamed 500 years ago.[13]

The following table is an attempt at a prognosis. It assumes that a state of "new normal" will be established in the 22nd century. The 21st century will be shaped primarily by far-reaching transformation processes. The perception

11 Wilson, Sheena; Carlson, Adam & Szeman, Imre (2017): Petrocultures: Oil, Politics, Culture. McGill-Queen's University Press.

12 Szeman, Imre et al. (2015): After Oil. Introduction. Online: http://afteroil.ca/resources-2/introduction/

13 Sachs, Hans (1530): Schlaraffenland. Online: http://www.wispor.de/w-g-sach.htm

Transformation of the energy system

Field	19th century	20th century	21st century	22nd century
Regulation	Regulation – what does that mean?	Regulation of the few for the benefit of all	Regulation of all for the benefit of all	Regulation – should be left to algorithms
Growth paradigm	Size matters: quantitative growth at all costs	Optimisation of supply: our electricity comes from the socket	Optimisation of demand: smart energy	Optimisation of humanity: humane energy
Energy mix	The first best nearest source of energy	Energy from all over the world, the price determines the mix-ture	As electrical and re-newable as possible	The best energy sour-ce from the area
What is scarce?	High quality energy	Cheap energy	Clean energy	Time
What is available in abundance?	Human labour	Fossil resources	Cheap energy	High quality, clean energy

Source: GDI, 2018

of humane energy as a growth paradigm and time as a scarce commodity spring from the belief that what is available in abundance becomes irrelevant. If we no longer need to worry about energy, we will worry about other things – fellow feeling, for instance, or time management.

Disruptive patterns

The question then is not whether we will reach the "new normal", but what will happen in the meantime. The path to energy abundance is fraught with surprises and uncertainty. Social and technological transformation never unfolds slowly and steadily, but abruptly. It can take place in numerous small events, such as the development of better and better computer chips, or in a few major events, such as the French Revolution in 1789 or the October Revolution in 1917. Each of these events opened up new possibilities and broke new ground, while burying old, established paths of development. Each followed its own logic or irrationality. Nonetheless, from past events, patterns can be identified that

> We must be mentally and institutionally prepared to derive the greatest possible benefit from the inevitable structural disruption.

indicate which major events will result in changed economic or social conditions. The following list, which does not claim to be exhaustive, highlights five of them:

- → **Fukushima events:** An external shock shifts societal demand for individual energy sources. This shift is the result of a reassessment of risk rather than efficiency concerns.
- → **OPEC events:** An international, economic shock changes the conditions of the energy industry. It is caused by supply shortages, price fixing, politically motivated actions or monopolies.
- → **Lehman events:** An international, economic shock changes the economy and social values. The attitude that things cannot continue as they are takes over. People, companies and institutions seek alternatives within and outside the system.
- → **Swissair events:** A national economic shock shifts societal priorities and values. Achievements that were deemed safe are renegotiated.
- → **iPhone events:** A new disruptive technology changes the economic conditions in many sectors. The higher the convenience factor of the new innovation, the faster and more intensely it is adopted.

In particular, the main focus of Swiss energy policy should not be on an attempt to prevent sudden, large-scale developments – the unfolding forces can rarely be controlled from Switzerland and they tend to be nigh on impossible to predict. The lessons learnt from past catastrophes are used primarily to prevent a recurrence of the same catastrophes: a new type of catastrophe can strike all the harder.

Instead, the main focus should be on the new developmental paths opened up by structural disruption. Further to Louis Pasteur's comment that coincidence favours only the prepared mind, we must be mentally and institutionally prepared to derive the greatest possible benefit from the inevitable structural disruption. Complex systems such as the energy system change only when forced to by sufficiently strong pressure.

A long-term method of using crises for tactical systemic changes was that practised successfully by the European Union. It was developed in the 1950s by the French entrepreneur Jean Monnet, one of the pioneers who paved the way for Montanunion, the predecessor of the EU. "Europe will be forged in crisis and will be the sum of the solutions adopted to tackle these crises," Monnet predicted. It takes an existential crisis to develop solutions that transcend national self-interest.

Monnet, one of the greatest networkers of his time, had developed his method for a small elite: the top officials of the European institutions in Brussels and their close advisers, and the closely related European experts in the national governments. They had a clear vision of the distant future: the "new normal" of a united Europe. But they were unable to realise their vision alone – only the heads of the individual member states could do that, who at the time were more interested in re-election than in the development of Europe. It would take a crisis summit to gather all these decision makers in one place. Gazing into the abyss, they would agree to one of those steps that would take Europe towards its future. "People accept change only under the pressure of necessity," Monnet believed – with the exception naturally of the members of his own elite.

The path: future shifts

Trend landscape

This section identifies and analyses important social, technological, economical, ecological and political developments that could shape the energy system of the future. They include likely predictions and hypothetical yet plausible events. Each development constitutes a shift: if it takes place, it will change the way in which we produce and consume energy. The illustration is our trend landscape. It shows as a type of radar the thematic latitude and the most important fields of development that will impact our energy system.

The shifts examined here vary in probability and impact, and this is reflected in the choice of coordinates used in the trend landscape: the x-axis represents the probability that a shift will occur. It also represents time: certain shifts will take place tomorrow, while others are still far in the future. The y-axis represents the impact a shift will have on entry into the energy system. Our illustration constitutes a current survey.[14] Due to the dynamic development of the entire energy system, the landscape will inevitably change over the years. Certain shifts will move upwards or to the left, others are eliminated and others are added.

[14] The illustration is based on the results of the GDI expert workshop on 27 February 2018.

30 Shifts on the way to the energy future

SOCIETY

- **Electrified lifestyle:** An electrified society races from one climax to the next, yearning for greater and greater intensity. We are insatiable and want more of everything.
- **Energy cyborg:** Our future energy lifestyle will go beyond sufficiency and voluntary energy thrift. People will become power plants, producing much of their energy requirements in or on their own bodies.
- **Environmental dictatorship:** A radical Green Party comes to power in Germany. It declares a state of emergency and draws all Europe into it. The new government implements personalised CO_2 budgets, temporarily restricting and strictly rationing energy consumption.
- **Helionauts:** Communal energy cooperatives are formed, with their organisational model based on participation and co-determination. Consumers can contribute financially to external, communal solar gardens. In return, they receive credit notes for any surplus energy produced by their share of a solar garden.
- **Population growth:** Over the next decades, the population of Switzerland will steadily increase to more than 10 million people. The country will gradually expand its energy system to handle the increased demand and to guarantee supply.

TECHNOLOGY

- **Autonomous cars:** Autonomous cars are shared rather than owned and ultimately supplant today's public transport. As a result, considerably fewer cars are on the streets, but they are used more heavily. Mobility remains a status symbol, but the car as a consumer product loses its significance.
- **Autonomous swarm energy:** Digitalised infrastructure leads to a fundamental restructuring of energy companies. Ultimately, it is conceivable that energy companies will no longer require human input. The energy system governs itself through artificial intelligence.
- **Big battery boost:** Large batteries allow energy storage for entire cities to offset fluctuations in energy production. The efficiency of these new storage options strengthens renewable energy sources and pumped-storage power plants will become less relevant.
- **Breathing microgrids:** The electricity providers lose their monopoly. Efficient, local means of energy production and storage enable decentralised power grids. As a result, neighbourhoods and energy cooperatives operate their own networks and become independent. Depending on requirements, they automatically join forces with others or separate. These breathing microgrids shift existing ownership and market structures.
- **Electrification:** The electrification of products and services boosts electricity demand.

→ **Laboratory meat:** Petri dishes replace farms: meat is produced artificially, using plant-based ingredients or bovine muscle cells. Less animal feed needs to be grown; land previously used for livestock farming becomes available for other purposes.

→ **Nuclear-free:** Switzerland decommissions its nuclear power plants and the proportion of nuclear energy will sink to zero.

→ **Smart contracts:** In particular, the energy industry sees blockchain as a new path that could revolutionise the energy system. Smart contracts automate and simplify the purchase and sale (or acquisition and feed) of energy.

→ **Smart heat grid:** Heat can be shared in the same way as electricity. Intelligent, local grids heat residential and commercial areas efficiently.

→ **Vacuum cleaners:** Unwelcome CO_2 is extracted from the atmosphere and stored in subterranean geological formations.

→ **Virtualisation:** The constant advancement of virtual and augmented-reality technologies shifts more and more activities into the digital sphere. Consumption patterns change and a real physical presence is no longer required for many experiences, such as business meetings.

ENVIRONMENT

→ **Cobalt shock:** A network of new storage options emerges. It gives rise to new material dependencies: raw materials used to produce energy (e.g. mineral oil, gas, coal) become irrelevant in the long term, while those used to produce storage media (e.g. cobalt, lithium) become crucial.

→ **Disaster displacement:** Climate change leads to more frequent and severe natural catastrophes and, in turn, more migration. Not only does this increase the population in the regions concerned, but also heightens global awareness of climate change.

→ **Glacial melting:** The warming climate destroys (nearly) all glaciers in Switzerland. This results in a loss of Swiss identity, more rock falls and new challenges for the affected regions. The economically prosperous Mittelland is no longer willing to finance the increasingly expensive protection and supply of peripheral regions.

ECONOMY

→ **Biological flights:** The imperative of clean energy will spread to sectors previously untouched by it, such as the air traffic industry. As its share of total emissions continues to increase, kerosene is replaced by other fuels, such as low-emission biofuels, hydrogen and electric drive systems. Airlines voluntarily offer compensation for emissions that cannot be prevented by these measures. What was intended as a communication measure develops into a valid business model.

→ **Divestment:** Switzerland recognises that its influence on the world is disproportionately greater than its size and begins to take on greater global responsibility. The government implements measures that reduce both its domestic emissions and its international footprint. As a result, all financial institutions in Switzerland are forced to invest in an environmentally friendly manner. If other countries follow suit, companies will have to become sustainable in order to be able to finance their products.

→ **Free energy:** As the marginal cost of renewable energies moves to zero, the same will apply to energy in general. Consumers pay for their energy with user data rather than money.

→ **Liberalisation:** Swiss consumers can choose their own electricity provider, which leads to more competition in the national electricity market.

→ **Motor city:** China becomes the "Detroit" of electric vehicles. Cars powered by fossil fuels lose their market share and disappear from the streets. This leads to an electrification of road traffic.

GEOPOLITICS

→ **Climate process:** Oil companies continue to contribute to climate change, while others bear the consequences. Coastal cities worldwide receive compensation after suing fossil-fuel companies for current and future climate change costs. The affected companies struggle to remain profitable, and insurance for high-risk business is increasingly hard to obtain.

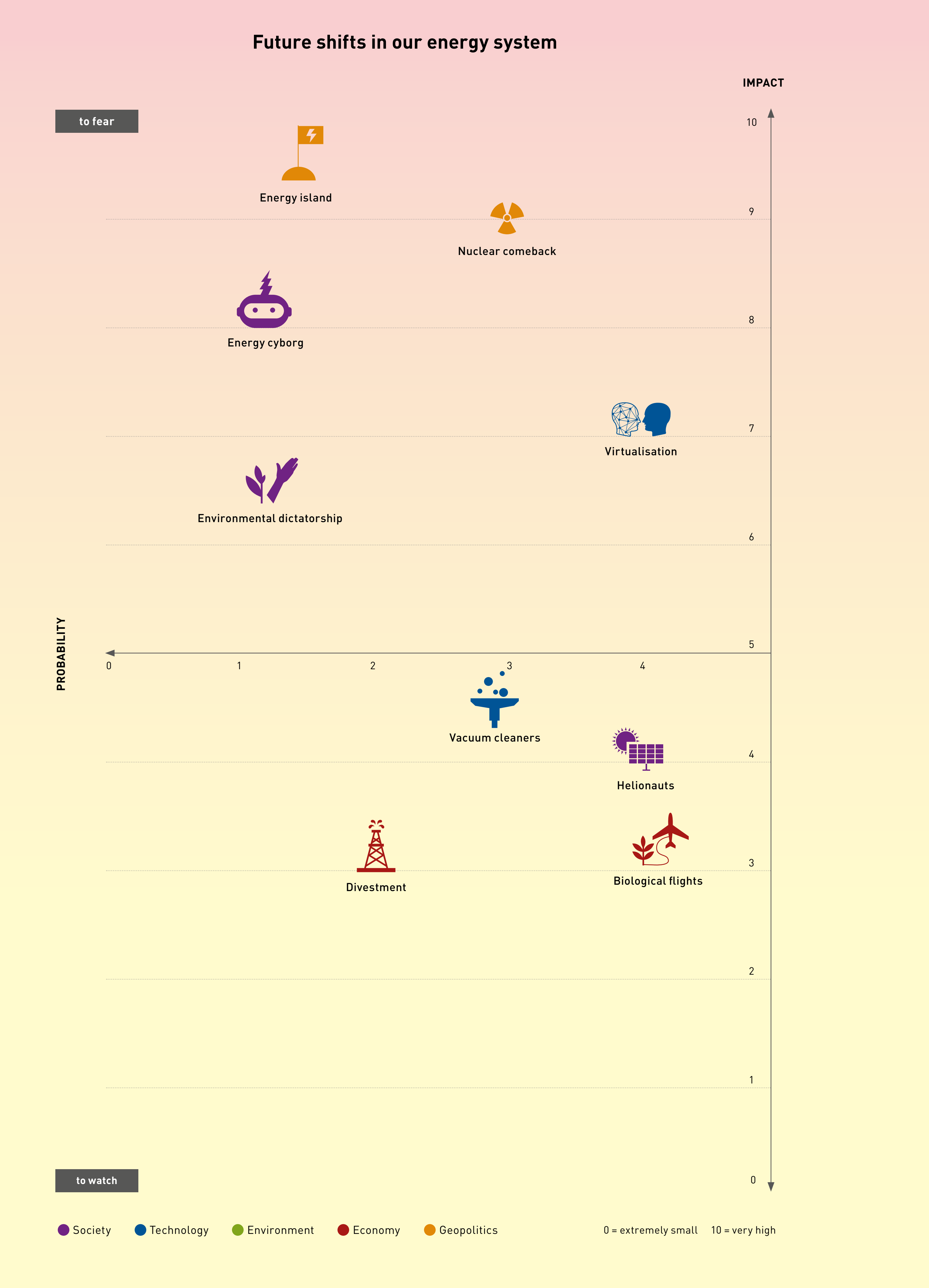
→ **Cyber attack:** An increasingly electrified and digitalised energy infrastructure makes the network susceptible to targeted hacker attacks. Potential consequences range from data theft and power cuts to the destruction of physical property and massive financial losses.

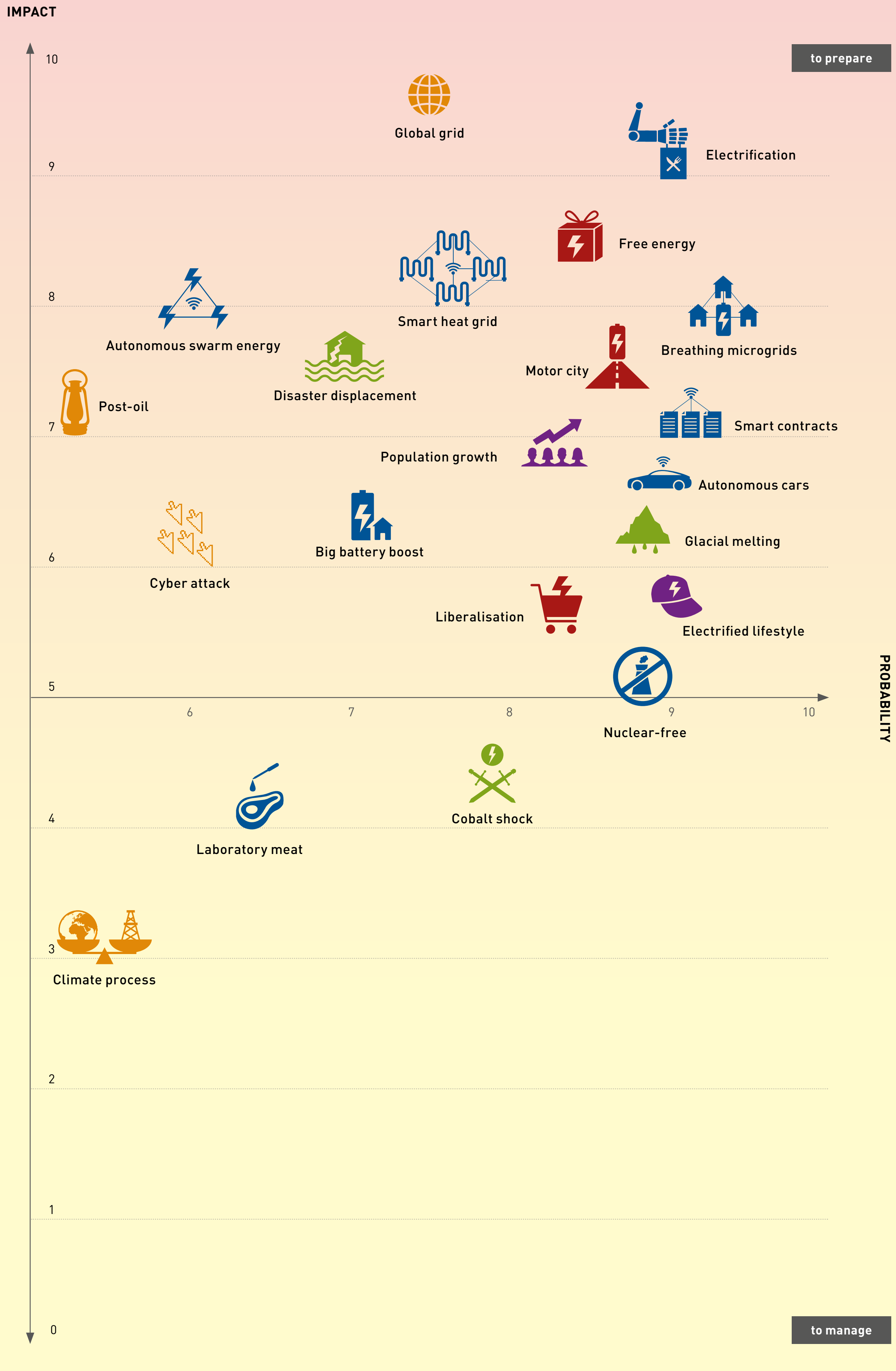
→ **Energy island:** In order to avoid dependency on other countries, legislation is passed that obliges Switzerland to provide a largely self-sufficient energy supply.

→ **Global grid:** The European electricity grid, which integrates the Swiss system, gradually expands and ultimately merges with other utilities to form a collective global grid. This allows the world's most efficient power plants and transmission technologies to be shared globally.

→ **Nuclear comeback:** Forms of energy that were presumed dead may experience a second or third spring. The nuclear industry may also face a renaissance, as it is considered an instrument of power in a central energy supply system.

→ **Post-oil:** Oil-fired heating sources are banned from buildings. This leads to a massive reduction of emissions in the building sector. Other systems such as heat pumps and district heating can largely prevent CO_2 and particulate emissions.


Future shifts in our energy system
IMPACT
to fear
Energy island
Nuclear comeback
Energy cyborg
Virtualisation
Environmental dictatorship
PROBABILITY
Vacuum cleaners
Helionauts
Divestment
Biological flights
to watch
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
Society
Technology
Environment
Economy
Geopolitics
0 = extremely small
10 = very high



Source: GDI, 2018

New energy worlds: zooming into the trend landscape

Shifts do not just happen. Even if it is an entirely unpredicted event, the change in the energy system that follows this event is the result of a variety of related actions and stances. None is purely coincidental. Managing this energy system will take more than determining and controlling the conditions in which it will operate. It will require preparation for potential errors and sensible plans for responding to setbacks.

The following section examines one development from each of the five categories of change (society, technology, economy, environment and politics) for a closer look at the shape of future energy worlds. The selected shifts vary in probability and impact and thus represent possibilities and not forecasts.

Society: Energy cyborg

Our future energy lifestyle will go beyond sufficiency and voluntary energy thrift. Humans will become power plants, producing much of their energy requirements inside or on their bodies.

The Netherlands builds massive dams to protect the country from the rising sea level. Bern plants the Croatian Turkey oak as a green lung for its residents in a future different climate. Both examples illustrate the importance of adapting to climate change. The same logic with which humans are modifying nature will soon be applied to ourselves; instead of changing only the world around us, we will change ourselves in the future.

THE NEW PROSUMERISM

The decentralisation of the energy system means that energy production will move closer to humans spatially and conceptually. The trend towards prosumerism is increasing; i.e. simultaneous (or successive) consumers and producers of energy. Current examples of prosumerism include solar panels on the roof, basement heating systems that supply an entire block of flats, shares in energy cooperatives and the commitment of energy-independent housing associations. Slogans such as "Off Grid!" or "Unplug!" advocate autonomous, self-sufficient energy lifestyles. Nevertheless, there will be movements that aim to go beyond sufficiency and voluntarily refrain from energy consumption. Just as technical progress can turn homes from consumers into producers of energy, people will be motivated to produce at least as much energy as they personally need.

THE ENERGY-INDEPENDENT HUMAN

New materials are likely to play an important role in the process of turning people into power plants. After all, the human body itself is a large untapped source of energy: just think of the seemingly infinite kinetic energy produced by human motion every day. Researchers from the University of Dallas have developed a new kind of thread in an attempt to harness this energy. The thread generates electricity through motion. "Twistron" is made from carbon nanotubes that generate electric voltage on expansion. The energy-producing clothing of the future could draw energy from the wearer's movement to satisfy low-level electronic requirements.[15] Shoes

[15] Kim, Shi et al. (2017): Harvesting electrical energy from carbon nanotube yarn twist. Science Vol. 357, ed. 6353, p. 773ff. Online: http://science.sciencemag.org/content/357/6353/773

"Stick-on power plants" can soon produce energy everywhere - whether as a label on a jam jar or as a tattoo on the body.

already exist that can generate energy from human motion.[16] "Stick-on power plants" could also play a crucial role.[17] Developments in the field of advanced functional materials – materials with special electric, magnetic or optical properties – will allow us to use adhesive, energy-generating film anywhere: as wallpaper, as a jar label, as a tattoo on the skin, or even as energy-producing solar paint on any conceivable surface. E-book readers or similar devices will no longer need to be recharged when they are made from advanced functional materials. The energy derived from ambient light, friction or motion will be adequate to power small devices virtually infinitely. In a few years, charging our devices on a daily basis, as we do today, will be a thing of the past.

HUMAN ENGINEERING

In a next phase, humans could conceivably progress from carrying a power generator on the body to carrying one inside it – an energy cyborg. In 2004, Neil Harbisson became the world's first cyborg. He was born with a rare form of colour blindness, but never accepted his condition. At the age of 20, he decided to connect an antenna directly to his brain. This has allowed him to perceive information that is imperceptible to others: he can hear colours, feel infra-red rays and even receive data from satellites. Harbisson is a co-founder of the Cyborg Foundation, which supports the use of implants in the human body with the goal of sensory extension.[18] The cyborg art movement believes that we have already merged psychologically with technology. The next step involves biological fusion of the body with technology. Technological enhancements can enable people to see in the dark[19] or change their thermal perception to reduce sensitivity to cold or heat. Ultimately, this could make heating and lighting fully obsolete.

Human imagination and possibilities are limitless: the American philosopher Matthew Liao raised the uncomfortable idea of genetically modifying the human body to make it more adaptable to climate change. Genetic manipulation to reduce physical size could lower food requirements, and it may be conceivable to directly implant a meat allergy or an empathy gene. Of course, this human engineering would be voluntary – albeit possibly supported by tax or healthcare incentives.

16 Rincon, Paul (2015): Smart shoe devices generate power from walking. BBC News. Online: http://www.bbc.com/news/science-environment-30816255

17 Reusswig, Fritz et al. (2014): energy2121: Bilder zur Energiezukunft. Klima- und Energiefonds. Omnium KG.

18 Cf. https://www.cyborgfoundation.com/

19 Cf. https://www.youtube.com/watch?v=TBmpwTYym2E / https://newatlas.com/biohackers-night-vision-eyedrops/36797/

50 SHADES OF GREEN

In future, people might copy an energy trick from their animal cousins. Elysia chlorotica, a species of sea slug, feeds on algae. Chloroplasts contained in the algae continue to live on inside the slug's body. This enables it to photosynthesise and convert light into energy. A technology based on this process could make us all a little greener. Although the amount of energy that humans could generate through photosynthesis is far from enough to power our lifestyle, this[20] "inner greening" could certainly become part of this lifestyle. Inspired by nature[21], future marathon runners might well move a little faster in the sun than they do in the shade.

Technology: Autonomous swarm energy

Digitalised infrastructure leads to a fundamental restructuring of energy companies. Ultimately, it is conceivable that energy companies no longer require human input. The energy system becomes a self-governing artificial intelligence.

In the next decades, digital technologies will upgrade our energy systems to make them more closely connected, intelligent, efficient, reliable and more sustainable worldwide. Developments in data processing, analytics and connectivity will bring us a range of new digital applications. However, this will not simplify energy management right away, but make it more complicated. First, more decentralised energy resources will be connected to the network. Increasingly, electricity will flow not only from large, central power plants to the end consumer – it will go both ways. This will bring new challenges. Second, billions of smart devices will be connected to the network, increasing the complexity of management considerably.[22] In order to control this complexity, the solutions will be outsourced to software more frequently.

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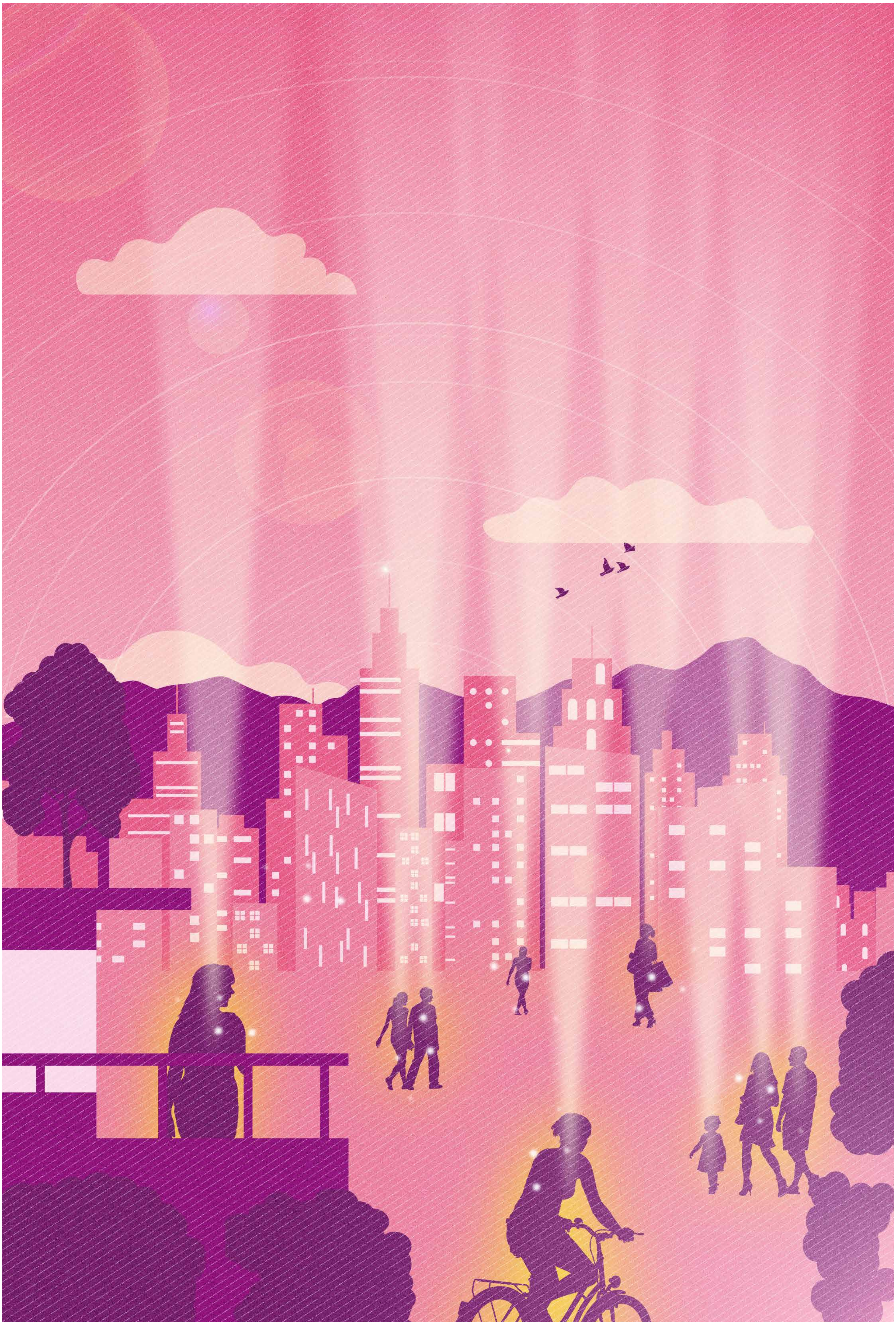
20 Stone, Maddie (2015): Eating the Sun: Can Humans Be Hacked to Do Photosynthesis? Motherboard. Online: https://motherboard.vice.com/en_us/article/3dk4bv/human-photosynthesis-will-people-ever-be-able-to-eat-sunlight

21 Cf. Martin, Richard (2016): A Big Leap for an Artificial Leaf. MIT Technology Review. Online: https://www.technologyreview.com/s/601641/a-big-leap-for-an-artificial-leaf/

22 Kroposki, Benjamin (2017): Basic Research Needs for Autonomous Energy Grids. National Renewable Energy Lab. Online: https://www.nrel.gov/docs/fy18osti/70428.pdf



> Artificial intelligence can make the energy system more efficient and sustainable without eliminating jobs.

DEMAND MANAGEMENT AND A TRADE PLATFORM

One such approach is the use of machine learning-based predictive models. They can predict the weather conditions in a specific region with almost absolute certainty. The system can be programmed to switch off non-essential devices whenever a low energy output is expected. This will lead to a priority hierarchy: a dialysis unit will be switched off later than a refrigerator, and those with low-cost electricity contracts can expect their air conditioning unit or electric blanket to be switched off in low-output phases. The UK's National Grid is currently in discussion with Google's DeepMind to find a way of using artificial intelligence to improve the balance between energy supply and demand in the UK. The goal is to reduce UK energy consumption by 10% without new infrastructure through optimisation and the use of AI alone.[23] In future, digital energy systems might be able to identify who needs energy and deliver it at the right time, to the right place and at the lowest cost.

The start-up WePower is another example. Although it does not produce energy itself, it supports investment in sustainable energy projects. Using blockchain technology, the company is working on a peer-to-peer network for renewable energy trading – in the knowledge that in today's structure this technology currently uses so much energy that a large-scale application is difficult.[24] Investors have the opportunity to invest in tokens issued by WePower. Each token obliges the producer to supply a specific amount of energy in future. This standardises the tokens worldwide and producers can negotiate with consumers directly without the involvement of an intermediary. Buyers benefit from the opportunity to buy (future) energy below market value. For energy producers, it is a way of gaining capital and liquidity.

[23] Murgia, Madhumita & Thomas, Nathalie (2017): DeepMind and National Grid in AI talks to balance energy supply. Financial Times.

[24] Hornigold, Thomas (2018): Let's Talk About Bitcoin's Insane Energy Consumption. SingularityHub. Online: https://singularityhub.com/2018/02/05/lets-talk-about-bitcoins-insaneenergy-consumption/

UNSTAFFED ENERGY COMPANIES

But this is just the start. As digitalisation can connect a virtually infinite number of decentralised consumers, producers and prosumers, it opens up completely new business models, some of which will not require any human input. Forerunners are already in use, such as street lamps that own themselves. They produce, obtain, store and consume their own energy. Surplus energy is used to pay for their maintenance and repair. This principle of "decentralized autonomous organisation" (DAO) can be applied to considerably larger systems, provided that future legislation allows unstaffed companies to have a legal identity.

DAOs will be particularly useful in the energy sector of tomorrow with many potential uses. In most cases, their tasks will not compete with work currently carried out by humans. The intelligent street lamp does not eliminate any jobs, but makes the current street lighting system more efficient and sustainable. Indeed, the energy future could give rise to new occupational fields that we can only imagine today. Solar gardeners might tend to the installation and maintenance of PV systems, energy artists find creative ways of using surplus energy rather than saving it, and energy technology ethicists evaluate new technologies to determine their suitability for public use.

SUPER AI

Of course, not all energy will be produced decentrally in the near future. But centralised and decentralised energy no longer need to compete on the market; instead, conceivably the two approaches could merge. This could be achieved through the use of artificial intelligence – more specifically, a network of artificial intelligence that coordinates production, consumption and network management. This geographically distributed network could span all layers of the energy environment, from smart appliances inside homes to continental high-voltage power lines. The central question is how these various algorithmic systems would communicate with each other.

A promising, similar network already exists: the virtual swarm power plant, which is a combination of various small and medium-sized plants into a single large unit. The bundling of decentralised plants allows economies of scale in distribution and a more accurate prognosis of production fluctuations. In Germany, the Norwegian energy company Statkraft operates a virtual power plant with a capacity of more than 10,000 MW, more than even the largest nuclear and coal-fired German power plant. It bundles and markets electricity from many smaller producers of renewable energy, allowing it to distribute and store this energy more efficiently. Ultimately, all producers on a continent could form a massive, virtual power plant, which would supply energy to all consumers on the continent as a single virtual bundled user. One single artificial intelligence – an energy brain, so to speak – would be responsible for the central coordination of the system and organise its decentralised provision of services – and much more efficiently than existing coordination institutions today.

Once the fixed costs are paid off, energy becomes ultimately available for nothing.

Economy: Free energy

The marginal costs of renewable energies are negligible, and the same will apply to energy in general. Consumers pay for their energy with user data rather than money.

The marginal cost is the cost incurred to produce an additional unit of a product after the fixed costs have been paid. Digitalisation and the internet have lowered the marginal costs of various products significantly. Music is one example of many: after a song has been produced, it makes no difference if 10 or 10 million people download it. The same principle applies to e-books, communication via social media and university lectures. In future, it will also apply to the energy industry.[25] The dominant view has long been that this concept can work only with digital products and can not be applied to the production of physical products. The emergence of 3D printers was the first sign of an expansion of the zero marginal cost society to other sectors of the economy.

In the energy sector, similar developments are possible wherever the basic infrastructure already exists and and where no fuel costs accrue. Energy production from oil, gas, coal, uranium or wood always involves fuel costs; thus, marginal costs. But the sun does not bill earth for the energy it sends in the form of light, heat, wind and waves. Expenditure on the manufacture and maintenance of the plants that use and distribute this energy are currently plummeting. Once the fixed costs are paid off, the marginal costs of energy shrink essentially to zero. Ultimately, energy becomes available for nothing.

Free energy will have an enormous impact on society. This applies in particular to countries where developmental efforts are currently limited by a lack of energy reserves. Energy would become ubiquitous in many parts of the world where this is not yet the case. In other places, electricity bills would vanish – and that is just the start. The production and transport costs of goods would decrease along with all other costs relating to energy-consuming production processes. This would allow us to use the money we currently spend on electricity for other purposes.

[25] Rifkin, Jeremy (2014): The zero marginal cost society: The internet of things, the collaborative commons, and the eclipse of capitalism. St. Martin's Press.

BUSINESS MODEL: FREE OF CHARGE

What would a business model for energy producers look like if energy were free? An example: A company installs solar systems and batteries free of charge. The energy is also free, as it is produced decentrally by the sun. In return, the company collects user data. The German company FreshEnergy is also working towards zero cents per kWh. Its approach is unique: FreshEnergy gives its customers a free smart meter that can receive and send data, such as tariff changes and energy consumption rates. Through analysis of the data, the company is able to identify the various household appliances and uses this information to increase efficiency; e.g. by identifying major energy drains and suggesting alternative uses or products. Instead of focusing on the kilowatt hour as the core product, energy consumption is merely data input in order to open up a new sales channel for various products; for example, via a partner network.

The sale of electricity thus becomes a vehicle to tap into new revenue streams that might be profitable enough to provide electricity free of charge. Other industries offer interesting case studies. The telecommunications sector now provides its traditional key product, landline calls, almost free of charge. Despite this – or because of it – it generates solid revenue and profits from other products, in particular mobile telephony.

A direct analogy is an energy company providing "landline heat" – i.e. heating for homes – free and charging its users only for "mobile heat" (unfortunately yet to be invented), which would allow consumers to maintain their preferred ambient temperature at all times, regardless of the weather.

Environment: Cobalt shock

A network of new storage options emerges. It gives rise to new material dependencies: raw materials used to produce energy (e.g. mineral oil, gas, coal) become irrelevant in the long term, while those used to produce storage media (e.g. cobalt, lithium) become crucial.

Energy is not always available when needed. Thus, surplus energy must be stored for later use. The increased use of fluctuating renewable energy sources, the finite nature of fossil fuels and the electrification of the energy system will create demand for additional storage capacity worldwide. This will lead to a distributed, diversified storage infrastructure of entirely new storage options. It will even be possible to tap directly into this infrastructure in the event of intermittent supply bottlenecks. The combination of all storage units – from small mobile car batteries to larger stationary batteries, major wind parks and solar plants – will create a huge energy storage potential. The connection does not necessarily need cables, either. The US Federal Communications Commission recently approved the WattUp system from Energous.[26] WattUp can charge electronic

[26] Energous Corporation (2017): Energous Receives Industry-First FCC Certification for Over-The-Air, Power-At-A-Distance Wireless Charging. Online: https://ir.energous.com/press-releases/detail/596/energous-receives-industry-firstfcc-certification-for

devices wirelessly over distances of several metres – energy is sent rather than transmitted. In future, energy-producing devices will communicate with energy-consuming devices. Taken to the extreme, this could be consolidated into a single global power plant in one place. It produces so much energy, it can distribute all the energy required to any location on the planet wirelessly. When we are able to draw energy directly from the air, plugging a cable into a socket will become obsolete.

THE END OF PUMPED-STORAGE POWER PLANTS

Ultimately, the new types of short-term and long-term storage units and large investment in new battery technologies could spread to a segment that is still considered a growth market: hydropower. For a long time, pumped-storage power plants were the only energy storage systems able to produce large volumes of electricity in a very short time to offset peaks in demand and supply gaps. When the new storage technologies are more efficient and economical, pumped-storage plants will eventually become a relic of the energy past. But they offer better options for reuse than other power plants: if the lakes are no longer needed to store energy, they can be converted into leisure parks.

COBALT SCARCITY

The rapidly growing demand for new storage options brings with it new material dependencies. Electricity may be immaterial, but its production is not. The chemical element cobalt (atomic number 27) is representative of the often neglected material aspects of the energy transition. Cobalt is a silver-grey, very tough heavy metal. Its properties lend themselves particularly well to the production of lithium-ion batteries. Demand for the raw material is set to increase considerably due to the predicted rise of electromobility: a typical battery of an electric car contains five to 10 kg of cobalt, while a smartphone has about 10 g. Cobalt resources are already highly sought-after: studies predict that cobalt supplies for battery components will become critical in the next 15 years.[27] This prospect is already impacting the present economy: cobalt prices have tripled within 16 months.[28] This pressure is set to grow as the major global car manufacturers increase their production of electric cars in earnest.

Most of the world's cobalt is produced in the Democratic Republic of the Congo, while the tri-border area of Bolivia, Chile and Argentina

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[27] Arrobas, Daniele et al. (2017): The Growing Role of Minerals and Metals for a Low Carbon Future. The World Bank. Online: http://documents.worldbank.org/curated/en/207371500386458722/The-Growing-Role-of-Minerals-and-Metals-for-a-Low-Carbon-Future

[28] Spector, Julian (2018): Battery Markets and Metals Markets Have Officially Collided. Greentech Media. Online: https://www.greentechmedia.com/articles/read/battery-marketsand-metals-markets-have-officially-collided

yields the largest amounts of lithium. If these rare metals suddenly become more important than oil, new areas of conflict will break out with geographical power shifts. Besides technical innovation, it is the risk of a cobalt scarcity that drives new business strategies. Apple, which relies on cobalt for its iPhone batteries, has entered into discussions with mining companies in the hope of a long-term sales contract. The tech giant wants to protect its flagship product from the effects of a cobalt shortage caused by electric mobility.

WATER IS NOT BLACKMAILABLE

For the operators of pumped-storage power plants, a battery crisis, whether triggered by a shortage of lithium, cobalt or another resource, would be a welcome argument. After all, they can offer proven energy storage options that are available at short notice without any need for raw materials – and without any potential for blackmail. But a serious cobalt shock will not happen. Scarcity leads to more expensive raw materials and at the same time boosts an innovative energy. More mining is inevitable, but increased recycling, substitution and careful design of new equipment will help satisfy the growing demand for cobalt. However, the risk of new dependencies will create enormous pressure to develop the next generation of batteries with lower amounts of (or, ideally, none) critical minerals. The proton battery is one option: instead of cobalt, it has an electrode made of carbon, one of the most widespread materials on our planet, and is charged by thermolysis. That makes it economical, environmentally friendly and rechargeable.[29] In addition, other new storage options with a minimal impact on the environment include hydrogen-based systems, fast-charging supercapacitors and compressed-air power stations.

Geopolitics: Nuclear comeback

Types of energy that were presumed dead may experience a renaissance. The nuclear industry, too, might be due for a renaissance, as it is considered an instrument of power in a central energy supply system.

Sometimes things change at breakneck speed and whole energy systems are turned upside down. Within just a few seconds, tectonic plates off the Japanese coast moved up to 27 metres horizontally and 7 metres vertically. The resulting tsunami hit the mainland and led to the Fukushima reactor disaster. This put pressure on the global nuclear energy industry; Switzerland even decided not to build any new nuclear power plants. Other forms of energy are not immune from catastrophe, either. On 8 August 1975, the Shimantan dam in China burst due to large volumes of water brought by an exceptionally strong typhoon. Half an hour later, at about 1 am, the massive wave toppled the Banqiao dam, too. Overall, 62 dams broke and more than 100,000 people lost their lives. Nearly 200,000 people had to be evacuated in California last year, when strong rains and poor maintenance threatened to burst the largest reservoir dam in the US.[30]

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[29] RMIT University (2018): All Power to the Proton: Researchers Make Battery Breakthrough. Online: https://www.rmit.edu.au/news/all-news/2018/mar/all-power-to-the-proton

[30] Fischer, Lars (2018): Warum Staudämme gefährlich sind. Spektrum der Wissenschaft. Online: https://scilogs.spektrum.de/fisch-blog/staudaemme-gefaehrlich/

Fear of disempowerment can give preference to large centralised power plants over small, decentralised systems.

Such sudden events can spell trouble for entire forms of energy. Other sectors of the energy industry are quick to fill the gap and profit from the crisis. But the opposite effect can occur just as fast: energy forms that were presumed dead experience a revival. Pellet systems and cosy fireplaces brought wood-fired heating back to people's attention, and the same might happen to nuclear energy.

THE POWER OF NUCLEAR REACTORS

The digitalisation of the energy industry is also driving its decentralisation. The more decentralised and democratic an energy system is, the lower the power of the central institutions becomes: this affects not only the central economic institutions, the energy companies, but also the central political institutions, the nation state. In theory, today's powerful could simply resign themselves to their loss of influence. But many will attempt to secure their power. The nation state and central power supply systems go hand in hand, even where nuclear power plants are not run by the state itself, but by sub-divisions, such as the Swiss cantons, or private companies as in Germany. This fear of disempowerment can give preference to large centralised power plants over small, decentralised systems. Those in favour of centralisation cite reliability of supply and low dependence on foreign powers as arguments for their case. Of course, this does not necessarily involve nuclear power plants. Regenerative systems can be instruments of power, too. The now-shelved "Desertec" project, which envisioned central solar energy systems in North Africa providing electricity to all of Europe, is one such example.

CAN NUCLEAR ENERGY SAVE THE WORLD?

Nuclear energy could also receive a boost from the fact that the energy transition is progressing too slowly to keep climate change within tolerable consequences. It is becoming increasingly clear that insistence on 100% renewable sources is associated with high costs and problems. A recent study by the journal Energy & Environmental Science found that solar and wind energy alone could cover approximately 80% of the US's annual energy consumption, but massive investment in energy storage and transmission technology would be required to prevent major outages. Nuclear power could certainly be considered as a transitional energy on our path to a fully renewable energy world. A condition would be that the risk of radioactive waste is perceived to be lower than that of climate-damaging gases. From today's perspective, however, the construction of new nuclear power stations looks odd. This aversion also extends to modern, relatively small fourth-generation nuclear plants, which run on thorium instead of uranium and are cooled with molten salt rather than water. After all, we are within reach of a renewable energy that does not generate a by-product so dangerous to human health that it must be locked away for a million years.

THE ETERNAL NUCLEAR FUSION DREAM

The threat of radioactivity could lessen in the future. In the second half of the 20th century, nuclear fusion was seen as a safe source of infinite energy. As in that largest of all natural fusion reactors, the sun, hydrogen nuclei fuse under high pressure into a helium nucleus. This process releases large amounts of energy that can be used to generate power. Fusion technology promised an endless supply of clean, safe electricity. And for many years it remained a promise. For five decades, we have heard that nuclear fusion will be achievable in 10 years and commercially viable in 50 years. But the finish line remains just out of sight. On the other hand, recent years have shown us many cases of the impossible becoming unlikely and then feasible virtually overnight.[31] We carry the world's knowledge in our pockets and we know the entire human genome. Why should it not be possible to kindle the fire of the sun on earth?

[31] The Guardian (2018): The Guardian View on Nuclear Fusion: A Moment of Truth. Online: https://www.theguardian.com/commentisfree/2018/mar/12/the-guardian-view-on-nuclearfusion-a-moment-of-truth

An energy future until 2050

The path to the future is not straightforward. Economic and ecological interests conflict with each other, technical innovation can aid or complicate the work of politicians, and things that are redesigned with the best of intentions often backfire. The interplay of steady progress and sudden jolts of development open up a wide range of options for public institutions – and just as many pitfalls.

As an example, this is illustrated in the following story of the European energy system from 2020 until 2050. In four acts and 36 scenes, it describes one of many possible developments in which the interaction and opposition of different forces leads ultimately to a safer, more ecological and more economical energy system.

First act

THE SMART LAST MILE

(2020-2025)

1. Europe develops an EU supergrid by 2020 – a syndicate of energy providers that predicts the available electricity supply and controls demand highly efficiently. Generation, storage and distribution are managed efficiently for both renewable and fossil energy sources. The proportion of solar and wind power continues to rise, reaching an average of total production of 30% by 2020. However, on the demand side, particularly in the heating segment, there is no improvement.

2. A Zurich start-up develops a technology for local heating networks based on heat storage and recovery. This yields an intelligent last-mile energy management infrastructure, named LastMileGenius (LMG).

3. Another company offers the BTM (Behind The Meter) technology, known from Tesla's Powerwall, to private households. It uses the LMG infrastructure to buy and store electricity and heat when they are cheap, and use or sell them when prices surge. Due to the price erosion of larger batteries, neighbours share battery units and trade stored energy with each other. This causes a drop in revenue for the primary energy producers. LMG and BTM merge and the resulting group, EnergyEdgeIQ, manages the local use of electricity and heat with its own trading system for exchange between neighbouring buildings. The company grows rapidly, selling its systems throughout the EU and subsidised by low-cost "green loans" for installation of these systems. Acceptance is high, as retrofitting does not require any significant modifications to buildings.

4. A cyber attack on the European supergrid at a critical time leads to a cascade of blackouts and severe consequential damage. Priority rules are rolled out across the European Union to ensure that critical infrastructures (such as renal units) continue to function during crises. EnergyEdgeIQ is forced to implement the new priority rules in its systems.

5. Criminals abuse the new rules on a massive scale by using counterfeit dialysis units to steal, store and resell electricity through the EnergyEdgeIQ system. The result is a renewed deregulation of the system and the introduction of a more market-based model. EnergyEdgeIQ develops automated electricity brokers.

6. The downside of the market system becomes apparent during the next major blackout: hospitals in rich countries outbid those in poorer countries. German streets stay lit while Bulgarian patients are dying. The resulting public outcry leads to new rules that combine market-based elements with a regulatory system. It maintains free cross-border energy trading while simultaneously guaranteeing the required amount of energy security. Citizens complain about the high level of bureaucracy involved, but ultimately accept it.

7. Conclusion of the first act: Energy consumption and costs have gone down. The system is prepared for market failure and regulation; it is more resilient to cyber attacks and sudden blackouts.

Second act

THE ADVENT OF "OPENENERGY"

(2025-2035)

1. After the first act, the energy sector has become the playground of two giants. On the supply side stands the EU supergrid, which organises the producers. On the demand side stands EnergyEdgeIQ, the system which help consumers optimise their energy consumption. It is a complicated, highly bureaucratic game of optimisation within a hybrid market-based/regulated system.

2. The EU supergrid is old. It lacks innovation and is burdened with a variety of supply-side regulations. EnergyEdgeIQ, on the other hand, is a young, aggressive enterprise (much like Amazon today). It exerts aggressive downward pressure on prices and strives for "energy without the grid". The EdgeIQ Premium programme (cf. Amazon Prime) issues energy credits to users in exchange for usage data from their smart home systems. This data intelligence gives the company an edge over the EU supergrid. As a result, some systems declare bankruptcy and supply is reduced.

3. Some environmental regulations are relaxed to prevent shortages, leading to term extensions of some coal-fired and nuclear power plants. After many years of decline, carbon dioxide emissions rise again. Environmental activists blame the energy corporations, which in turn blame EnergyEdgeIQ and its price erosion tactics. But EnergyEdgeIQ has established a green, socially responsible brand image over many years, and energy consumers are on its side.

4. Disgruntled former employees/whistleblowers break into EnergyEdgeIQ's systems. They publish managers' emails and videos to prove that the green image is merely a cover to maximise profits and push out the competition. The following shitstorm (cf. Facebook) turns public opinion. Both customers and environmental activists demand greater transparency in the EdgeIQ Premium programme and in the artificial intelligences that organise energy trading.

5. Anti-monopoly proceedings are initiated against EnergyEdgeIQ and the company is banned from using some of its technologies. The board of directors proposes an unusual idea: by 2030, EnergyEdgeIQ would "own itself", effectively becoming a company without employees.

6. EU-wide "energy AI standards" are passed that oblige both suppliers and consumers to facilitate external audits of their AI codes and make their data and code available to the public (open source).

7. The resulting system, "OpenEnergyNet", provides free, open and public access to the data and codes of the energy system, from the producer to the last mile. Private programmes, such as the EdgeIQ Premium energy credit system, are abolished and instead EU citizens and companies receive EU energy vouchers in exchange for data sharing. The media dubs the system "EnergyEuro". After a long and heated debate, all countries on the EU supergrid join the system as suppliers and consumers.

8. This prompts a massive open-source renaissance in the energy sector. A number of start-ups, many of them based in Zug's Crypto Valley, come up with various ideas for use of the available data and code. Open-source products and small start-ups take over an increasing share of the internal company functions of EnergyEdgeIQ.

9. By 2030, EnergyEdgeIQ is reorganised into a DAO (decentralised autonomous organisation). The former large corporation transforms itself into a string of peer-to-peer companies using the EU energy blockchain, based on an internal economy of energy tokens. This EU-funded structure is called "OpenEnergyNet", where each country/region operates its own energy company that trades with all the others. Countries outside the EU start to implement the "OpenEnergyNet". Gradually, the world's energy systems become self-owned companies.

Third act

MOBILE AND WIRELESS

(2035-2040)

1. In the meantime, the revolution of self-driving electric cars has made gradual progress. The charging infrastructure has expanded all over Europe. New, autonomous services are introduced; in 2030, more than 20% of all journeys are made in self-driving electric cars.

2. A car rental company invents "car clouds", which essentially combines vast car parks with batteries. These clouds are located in particularly cheap energy markets and are programmed to charge at the cheapest time. Their share of total energy consumption rises rapidly.

3. Another company invents a technology that carries electricity wirelessly between cars. This car-to-car system allows a car to trade energy with the car standing next to it in the car park. As a result, the market share of car cloud companies decreases, as more and more independent vehicles use the car cloud infrastructure if necessary, but otherwise manage their profits from the energy trade themselves.

4. Another company comes up with the idea of connecting the car-to-car system with buildings, and starts laying short-range power cables between smart intersections and adjacent buildings. This enables the exchange of electricity between cars and buildings while cars wait at traffic lights or stop for any reason. These smart intersections have batteries buried in the ground, which fuels a new boom in battery demand. They act as distributors, buying surplus electricity from buildings and cars to sell to other buildings and cars – or to autonomous automatic street lights. This development is similar to today's stock exchange high-frequency trading, where AIs carry out thousands of small transactions to make a profit.

5. These latest innovations closely link the traffic and home energy systems. Due to the nature of the OpenEnergyNet system this leads to huge new efficiency gains, price falls towards zero and more pressure on producers.

6. In line with Jevons paradox (increased efficiency boosts demand), energy consumption rises as producers' margins fall. As mobility is nearly free, people start taking their autonomous cars everywhere.

7. A major governmental rescue mission for the financially stricken energy producers enables them to close down nearly all fossil-fuel power stations. They also receive funding to renew the ageing solar and wind power infrastructure and increase storage capacity on the supply side through, inter alia, the replacement of outdated batteries. A far-reaching modernisation programme sweeps through the industry.

8. New government incentives encourage many start-ups to work on improving the supply side of the energy system in order to keep up with the disruptions on the demand side. As a result, revenues increase and electricity costs rise slightly, but are still significantly lower than before. Demand remains unaffected.

Fourth act

COBALT SHOCK AND FREE ENERGY

(2040-2050)

1. A major war in Africa destroys large parts of the cobalt production facilities; other important mineral supply chains are also disrupted permanently.

2. China, India and Latin America expand their own OpenEnergyNet infrastructures on a massive scale and begin to outbid the EU in the competition for the shrinking cobalt and battery reserves.

3. This leads to a supply shock for the EU and its energy modernisation programmes. The timing is devastating, as Europe is in a period of completely unpredictable weather and climate crisis. Its energy AI systems, which are based on weather forecasts, are performing poorly. This combination of forecasting errors and insufficient storage capacity causes incalculable network outages. The problem is considerably harder to manage than the hacking attacks in the first acts, as nature is the culprit.

4. The smart intersection companies are hit hard by the crisis, too: after being lavished with growth capital by the stock market for so long, they suddenly find their growth plans in question. As, in the classic American business style, they made high losses in order to gain as high a market share as possible in the new infrastructure market, the entire business model becomes shaky. A massive crash in the energy industry spreads to the financial markets.

5. Depression grips the EU energy market for many years. Prices become unpredictably volatile, there are many bankruptcies and an increasing rate of outages and accidents. The open-source technology behind the DAOs and AI systems aggravates the situation further, as technical errors pile up that no one fixes. The performance of the self-owned companies declines, with a number of prominent failures.

6. As the result of a severe backlash, some EU regions resort to old-fashioned "non-smart" grid infrastructures, while others go as far as banning smart intersection technology and all the hip last-mile markets.

7. The cobalt shock exerts enormous pressure to develop better substitutes, particularly in the US where a new generation of batteries is in development based on hydrogen fuel cell technology, and thus less dependent on critical materials.

8. At the same time, there is a breakthrough in blockchain and AI technology. The energy demand can now be met much more flexibly and with considerably reduced storage requirements, even in the face of unpredictable weather and consumption patterns. System efficiency rises as the demand for raw materials decreases.

9. A new start-up invents a technology to enable battery-free smart intersections. Vehicle route optimisation allows them to trade energy between vehicles and buildings without the need for buffer storage. People are willing to travel slightly longer routes to "receive" and "deliver" energy.

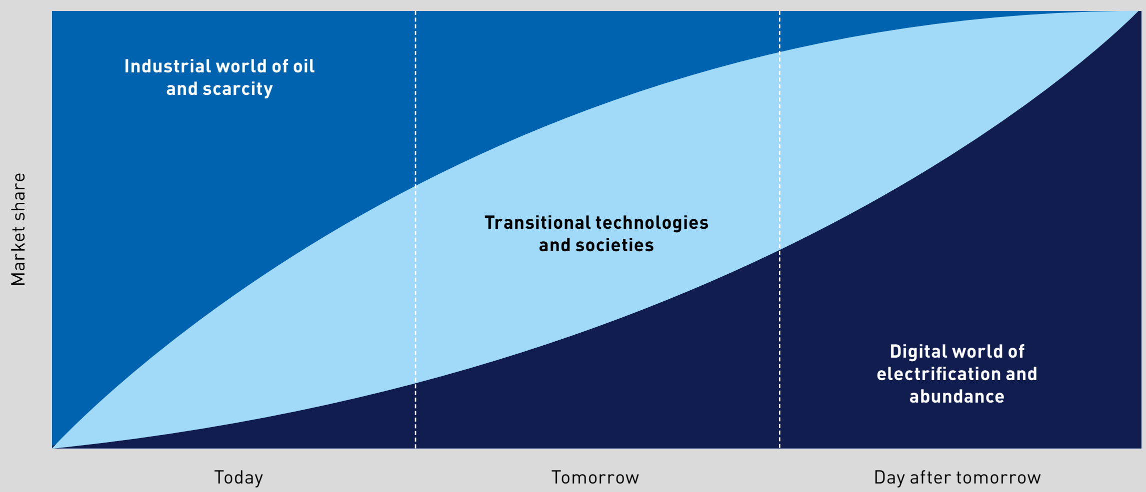
10. Thanks to the combination of new battery technology, an overall reduction in storage requirements and special "battery-free" last-mile markets, the energy market finally recovers from the effect of the cobalt shock.

11. All these innovations have made energy on average almost free to use, and there is such a massive surplus that cars and buildings are paid to use or store it.

12. By 2050, the EU is well on the way to deep decarbonisation, with Switzerland playing a key role. Although still a far cry from the utopian "new normal", all intermittent problems have been solved and the transformation is on course. Europe is well positioned to act as an innovation leader in the energy sector for the remaining half of the century.

The consequence: Lure of plenty

The transition in the energy system



Source: GDI, 2018

The future of energy beckons with a seductive vision: a digital world of electrification and abundance replaces the industrial world of oil and scarcity. A highly productive and efficient energy system makes energy available at any time, anywhere, and 100% renewable. As much as this vision coincides with long-term trends in technological development, it also radically rejects many established thought patterns. The energy sector was and is the prime example of the ecological limits of growth; energy conservation is considered the core virtue of the enlightened, committed person. It will take a long time to soften and change these behavioural and thought patterns, but they will ultimately become obsolete in a society of energy abundance.

What will take its place in the future can not yet be answered. How will cultural and social values change in an energy-abundant society? Will hunger, thirst and deserts be eliminated through use of desalination plants that can use any amount of seawater? In a life of energy overload, will more and more energy be consumed – simply because it is available? Will new scarcities and inequalities emerge to prop up traditional social structures? Or will abundance shift the focus from the quantity of goods to the quality of life?

No crystal ball can tell us the answers to these questions. They will emerge in that transitional society that lies between today's scarcity and the abundance of the future. Just like the energy system progresses along a string of transitional technologies, this transitional society will have to emerge. It will experience, advance and, ultimately, facilitate the transition. We cannot simply kick back and relax. Technological progress alone will not take our energy system into the future. The human systems of politics, economy and society are equally important.

State institutions will play a leading role in our transition for three key reasons. The first reason is purely material: in an electrified world, the nation state will become more important, as globally most power grids are state-owned. The second reason is economic: who will invest in an energy system from which ultimately no profit can be made? Only an institution to which the economic benefits are more important than the economic gain – the state. The third reason is political: the development towards a society of abundance will happen mainly through crises and upheaval. In such situations, even the most liberal societies call on the state for help almost automatically. Technical disruptions, social revolutions, environmental catastrophes: every shift in the energy industry is an opportunity for action, no matter if it is caused by humans or nature. It is a change to make our energy system more resilient and sustainable.

But these areas also look different than before. In the past, control of the big players was the most efficient instrument available to state institutions. Big business and big government were "frenemies", so to speak. This will change radically in the transitional society. Hundreds of thousands of new producers will enter the market; prices and quantities will fluctuate wildly; technical standards will struggle to keep up with technological change; opportunities to manipulate the system will increase in sophistication and diversity. Regulation will have to become faster and more flexible, without neglecting the basic need for energy security.

If the most efficient organisational tools of the energy future will be action and reaction during emergencies, how does one navigate this space? We see two approaches here.

In cases where the direction of a solution is clear and easily conveyable: the Monnet method

Even clear solutions can not be implemented if the economic incentive and/or political will is lacking. According to the method of European integration[32], the dynamising force of a crisis can help: only when all parties have looked into the abyss that threatens them if everything stays as it is, will they be ready for change. Whether the crisis is initiated deliberately or simply happens makes little difference to the success of this method – the crucial element is a clear understanding of the changes that are to be achieved as a result of the crisis.

In cases where the best way out of an ongoing crisis is unclear or disputed: the bacteria method[33]

Unlike humans, bacteria develop an overflowing creativity in stressful situations. "Bacteria under stress expand their horizons to overcome stress," says Regine Hengge, a microbiologist at the Humboldt University of Berlin, who has been researching stress in E.coli bacteria for decades. In crises, a special protein activates large, normally defunct parts of the bacteria's DNA, which then synthesises different proteins dozens of times. Since the bacterium does not know – cannot know – which specific problem it has, it cannot find a specific solution. Instead, it produces a plethora of possible solutions, in the hope that one of them might help it eliminate the danger or adapt to the new situation. "It prepares for the unexpected," Hengge explains.

Complex systems, such as companies or societies, can use the bacteria method with a good chance of success if there is no simple solution – or no solution at all – to a given crisis. All systems have a large number of unused or insufficiently used potential and capacities. An experimental, offensive strategy could activate these in order to solve the system's gridlock and perhaps even turn numerous small solutions into one big solution that nobody imagined before. However, this would require, at least occasionally, a much greater flexibility of regulatory institutions than at present.

Switzerland alone cannot shape the future of energy. The developments influencing this future are globally intertwined. But Switzerland could well be a pioneer in this process. It is a particularly regenerative, innovative country. It has leading international companies in the energy sector and a well-positioned research landscape both in breadth and quality. It is integrated into the European energy grids, but not bound by the often cumbersome regulations of the EU. This puts Switzerland in an excellent starting position for the energy-abundant society of the future.

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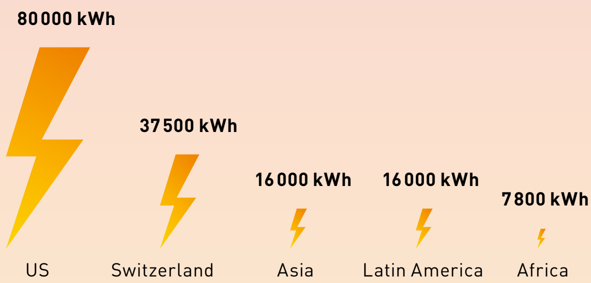
32 Cf. chapter "From normal to new normal".

33 Cf. the description of the "E.coli method" in: Friebe, Holm & Gürtler, Detlef (2018): Clusterfuck. Hanser-Verlag, pp. 246ff.

Appendix

On the state of the energy environment



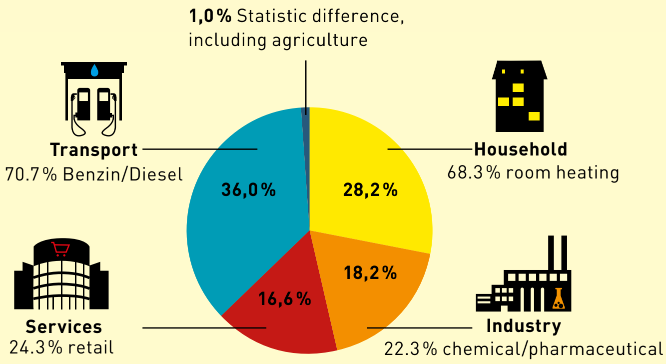
ENERGY CONSUMPTION PER CAPITA[34]
According to prognoses by the International Energy Agency, these values will equalise in future. Although energy consumption will decline in Europe and North America, it will increase in the rest of the world.[35]

PRICE EROSION
In 2016, the World Economic Forum pointed out that in more than 30 countries, non-subsidised, renewable energy is cheaper than energy generated from fossil fuels – and this will be the case in most countries around the world by 2025.[36]

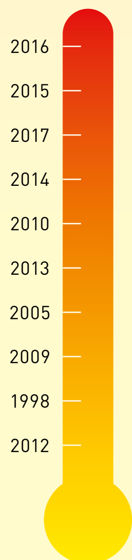
+1.06 BILLION PEOPLE
More than a billion people lack access to electricity. In its Sustainable Development Goals, the United Nations is committed to providing all humans with secure access to energy and increasing the proportion of renewable energy by 2030.[38]

30 %

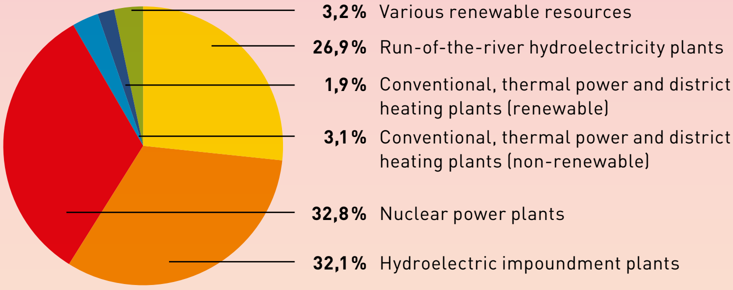
DO WE NEED LESS ENERGY?
Modern devices are increasingly efficient. By 2035, the current level of energy consumption will be cut by about 30% thanks to more efficient use and more economical devices. The greatest savings potential is in the building sector: sustainable refurbishment of existing buildings can reduce the consumption of room heating and hot water by at least 50%.[37]



WHAT DOES SWITZERLAND USE ENERGY FOR?[39]
The largest increase was recorded by the transport sector: 13-fold since 1950.

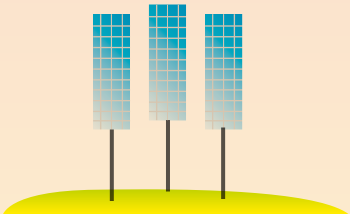


THE HOTTEST YEARS IN HISTORY (FROM 1880 - 2017)[40]
The global average temperature is rising. The last few years have been some of the hottest years ever.



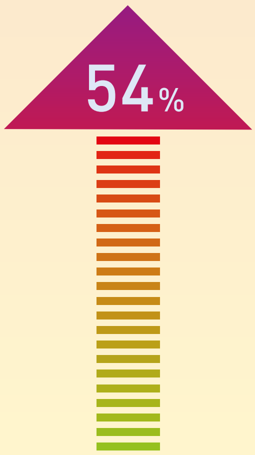
ELECTRICITY SOURCES[39]
Swiss electricity sources in 2016.

AIR TRAFFIC
More and more people fly. Swiss air traffic will account for over 22% of Switzerland's climate impact in 2020, an increase of 4% compared to 2016. Globally it looks even more extreme. The European Union predicts that international air traffic will grow sevenfold by 2050.[42]

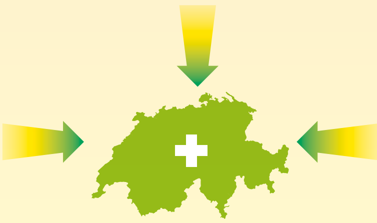


TRANSITIONING TO ENERGY ABUNDANCE
Assuming a constant growth rate (2016 = 50.7%) of solar energy, arithmetically when would our entire (current) energy requirements be covered by the sun? In 2030. What if global energy requirements continue to grow by 10% every year? In 2034.

POWERFUL SUN
Every day, the sun delivers 5,000 times more energy to earth than is needed during the same period. This means that in two hours, the sun radiates as much energy to the earth's surface as the entire population of the planet uses in one year.[43]



WORRY BAROMETER
According to a survey conducted by the Pew Research Centre in 40 countries in 2015, 54% of the world's population (global median) are convinced that climate change is a serious problem. But this concern is not distributed equally: countries with the highest per-capita emissions are least worried about climate change and its potential effects.[45]



GLOBAL ENERGY
While high-income countries tend to import energy, low-income countries are usually exporters of energy. Switzerland, for instance, imports three quarters of its energy.[39]

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Experts

The following experts contributed to this study. We have taken the liberty to expand on the good ideas and productive comments we received for this study. The content of this study does not necessarily reflect the opinions of the people listed here. Thank you very much for your valuable contributions!

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