The global context for Swedish steel industry in 2050: Four possible scenarios

Background report for 2nd workshop, Sep 1-2 2015

Karl Hallding, Henrik Carlsen, Kristian Skånberg, Nina Weitz, Stockholm Envirobnment Institute

The purpose of this report is to provide background for the 2nd workshop in the project "Swedish Steel Industry for Increased Community Value".

During the workshop participants will be divided into four groups, each group being responsible for developing strategies and actions that could enhance Swedish steel industry's opportunities to reach its visions under one of the scenarios. The process will be facilitated. Further reading instructions is distributed through e-mail invitation follow-up.

The document contains the following sections:

1 Introduction

1.1 Project objectives

The Swedish steel industry has developed a long-term vision for 2050 that communicates the industry's intention to play an active role in the shift towards a sustainable society by taking responsibility for both people and the environment. The vision emphasises three key commitments: excellence in technical development and engineering, creativity for new solutions, and that all output should bring value to society. While the two first commitments assert the industry's dedication to be at the forefront of technological and innovative development, the third commitment expresses a boundary condition for the industry's devotion to transform its operations and business models to meet the targets of the vision.

Two important challenges are implicitly embodied by the vision. Firstly, global and regional developments in the 2050 perspective are characterised by considerable, growing uncertainties. This requires a dedicated effort to review, reconsider and rethink how steel could add value to society in relation to a set of contrasting future narratives. Secondly, the boundary condition to ensure that the industry's output add value to society is vague and ambiguous. Therefore, in order to be able to measure and steer towards products, operations and business models that ensure maximum value to society, the contours of this concept need to be developed.

During 2015, Stockholm Environment Institute (SEI) and Jernkontoret are undertaking a participatory research project to further explore these two challenges. The project employs an explorative scenarios approach in order to capture key uncertainties in the timeframe up to 2050 – with the objective to maximize opportunities and minimise threats for Swedish steel industry. The work covers identification and robustness analysis of a range of options for Swedish steel industry to work towards its 2050 vision, against a wide array of trends and uncertainties bundled into a set of scenarios.

The work is guided by the following focal question:

> *Considering the mounting uncertainties about global and regional developments, coupled with firm indications about growing public and consumers' demands for clean production and innovative sustainable solutions, which are the most promising opportunities for Swedish steel industry to stay competitive in a market place with rapidly changing*

conditions and new actors, while ensuring that all output brings value to society?

The work is organised around two major workshops, each bringing together about 30 experts and stakeholders of various background, representing different perspectives on the future of Swedish steel industry. The two main workshops serve different purposes and the profile of the participants is somewhat different, with about half of the participants remaining from the first workshop while the other half represent new competences.

The first workshop took place on April 28, 2015 and focused on brainstorming different drivers and uncertainties that are important for the Swedish steel industry in the period up to 2050. Based on the outcomes of the workshop a smaller scenarios team at SEI has developed a scenario framework – presented in this report – to be used as a point of departure for the second workshop to be held September 1-2, 2015. The second workshop will use the scenario framework as a point of departure to generate proposals for strategies and actions that have potential to develop and promote Swedish steel industry.

1.2 The project work process

From start to finish, the work process consists of five steps. This report is written at the stage of finalising step 2 and 3 working toward step 4.

1. Identification of key drivers: The first step covers identification and analysis of a range of drivers and factors that are judged as important for setting the context in which Swedish steel industry will operate in the period up to 2050. The first one-day workshop (see 1.3 below) served as the key event for brainstorming drivers and to analyse, cluster and prioritise these into a smaller set of meta-drivers. During the workshop a few embryonic scenario narratives was also elaborated and tested. After the workshop the project core team has worked off these outcomes to develop a scenarios framework.

2. Development of scenario framework: The second step involves generation and elaboration of narratives for a scenario framework that depicts four inherently different futures that are relevant to the Swedish steel industry. The work has been carried out by the project's core team over several iterations through a series of smaller workshops. The scenarios are documented in text, images and graphs (this report) and circulated to the participants of a second workshop to provide the context and point of departure for identification of topics and areas for further action.

3. Elaboration of indicator framework for assessing value to society: As a third step, carried out in parallel and closely coordinated with the development of the scenarios framework, an indicator set has been developed to illustrate in qualitative and quantitative terms the developments in each of the scenarios. The indicator set is also used to ensure consistency between the scenarios. A key question in this work is to elaborate an approach for assessing how different lines of actions could bring about value to society.

4. Identification of topics/areas for further action: The fourth step comprises identification and analysis of topics and areas with potential to further Swedish steel industry in line with the vision. The second workshop is organised to generate ideas and suggestions for actions with potential to develop and promote Swedish steel industry. Starting from the preconditions set by each of the scenarios, a variety of ideas will be suggested and discussed e.g. topics for further research, communication needs, potential alliances, relations to customers, suppliers, governments and other stakeholders, etc. The ideas and proposals will subsequently be tested against each of the scenarios in order to analyse robustness and viability. Finally, the ideas will be clustered and prioritised. The workshop results will be further analysed by the project core team in order to arrive at set of optional choices for a coherent programme with topics and areas for further action.

5. Formulation of coherent action programme ("roadmap"): In the final step the proposal for specific topics/areas for further action will be further analysed by working groups consisting of researchers and representatives from steel industry and its key stakeholders. The final objective is to produce and communicate a coherent action programme on how Swedish steel industry could develop and strengthen its robustness and capacity while ensuring that all output add value to society.

1.3 Workshop 1 - the basis of the scenario development

The first workshop formed the basis for the scenario development. On April 28th, a group of 30 experts participated in a full day scenario exercise focused on drivers and uncertainties of the development of society in general and steel industry in particular. Using a facilitated brainstorming method the group jointly arrived at 21 clusters of drivers and prioritised 12 of them as the most important and uncertain:

1. Environment and climate change
2. Global power structures
3. Future resources – access or scarcity
4. New technologies and business models

5. Energy – accessibility vs. price
6. Demography
7. Infrastructure and transports
8. Urbanisation
9. Consequences of digitalisation
10. The financial system
11. International trade
12. Environmental governance

In order to be meaningful as input to the scenario development the drivers need to be further explained and detailed in terms of the different future states that the driver could take in the period up to 2050. These states could be qualitative or quantitative, and could be either nominal or ordinal. The process of developing states is further described in section 2.1 below. Participants further identified two to three plausible states of each of the 12 drivers for 2050, and sketched how a combination of three drivers (selecting one state from each driver) could play out in 2050. As a result, Workshop 1 provided the core team with a set of preliminary drivers, possible states and early ideas for storylines of how several drivers could interact. These components constituted the entry point for the work of a smaller SEI led scenarios team to develop the set of four scenarios presented in this document. The process and outcomes of Workshop 1 are documented in a separate workshop report that is available upon request.

2 Development of scenario framework

The development of the scenario framework is based on the list of drivers, plausible states and scenario sketches from the first workshop. During the process of constructing the scenarios set, two different quantitative techniques have been employed to ensure that the scenario set is relevant, plausible, and representative. First, a *cross impact balance analysis* (CIB) was carried out to ensure consistency within and between the scenarios. Thereafter, a *scenarios diversity analysis (SDA)* was employed to make sure that the set of four scenarios selected is able to span the array of possible futures as broadly as possible. The methodologies used to construct the scenarios set is further detailed in Appendix A: .

During the process of *cross impact balance* analysis the set of 12 preliminary drivers that came out of Workshop 1 was reviewed and revised into a set of 14 drivers. As illustrated in Figure 1 below these drivers were grouped into five clusters. The first cluster has an overarching position as these provide a global context in which the other drivers play out.

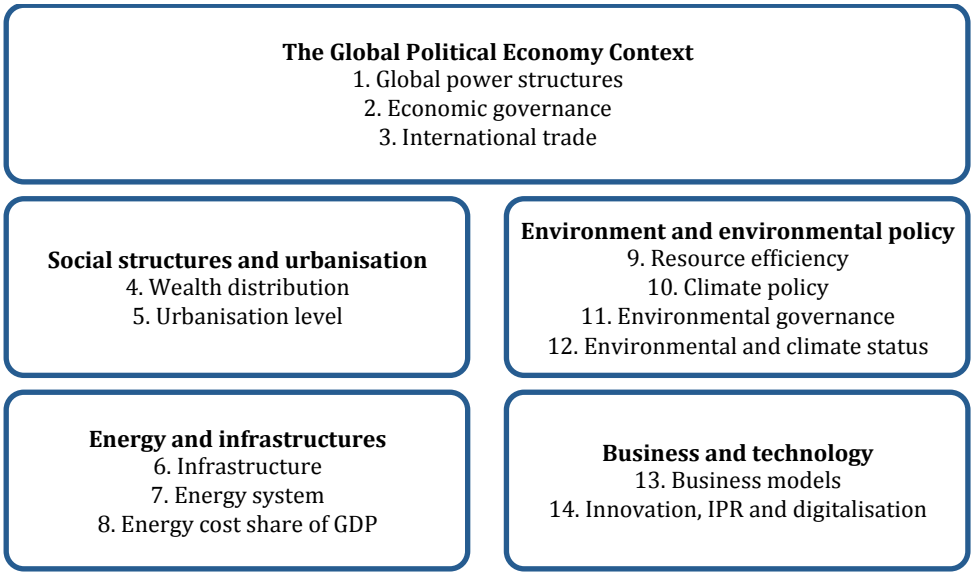

Figure 1: The 14 drivers divided into clusters

2.1 Drivers and states

While Workshop 1 generated indicative suggestions for states that each of the drivers could take, the cross impact balance analysis provided a foundation for refining and adjusting the states to ensure a balanced set of states for each driver. The complete list of drivers and their associated states (bullet lists) is presented in the following sections.

GLOBAL POLITICAL ECONOMY CONTEXT

Global power structures: The pattern of power and initiative that defines global developments.

- *Transatlantic leadership* – A revitalisation of transatlantic cooperation provides global leadership.
- *Global disorder* – Global structures have fallen apart and there is no strong coordination between actors.
- *Globalised without borders* – A highly globalized structure where comparative advantage is the key driver of global developments.
- *Multipolar* – A global structure defined by a limited number of power nodes with partly separate ambitions and covering different realms.

Economic governance: The type of economic governance that characterises global developments.

- *Government driven* – Governments play a central role in regulating the economy and providing investment capital.
- *Fragmented* – Different types of economic governance and a lack of cooperation and coordination between different systems.

- *Market driven* – The market plays the dominating role in how resources are allocated.
- *Decentralised polycentric* – Diverse types of economic governance coexists side by side and there are a number of different economic nodes that provide coordination.

International trade: The patterns and characteristics of global trade.

- *Green trade* – Only zero or low emission modes of trade takes place.
- *Fragmented trade* – Global trade is uncoordinated and inefficient using different modes of transportation.
- *Open global trade* – No particular rules apply and global trade systems are open and efficient.

SOCIAL STRUCTURES AND URBANISATION

Wealth distribution: The wealth distribution driver is expressed here in qualitative terms as the development of the middle class. It could also be expressed numerically as a Gini coefficient[1].

- *Large global middle class* – Global middle classes are large and poverty has decreased/decreases.
- *Stagnated global middle class* – The rise of the middle classes has come to a halt and begins to decline, with higher rates of poverty as a result.

Urbanisation: The urbanisation rate is given in qualitative terms with reference to the current urbanisation level.

- *Low* – The level of urbanisation is lower than in 2015.
- *Medium* – The number of urban citizens continues to grow, but at a slower pace than 2015.
- *High* – Continued strong urbanisation.

ENERGY AND INFRASTRUCTURE

Infrastructure: The type and level of infrastructure investments

- *New Climate Economy* – Green and low-carbon infrastructure dominates all infrastructure investments following the pathway charted by the New Climate Economy project[2].

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[1] The Gini coefficient expresses the extent to which the distribution of income (or consumption expenditure) within an economy deviates from a perfectly equal distribution.

[2] The New Climate Economy (newclimateeconomy.org) is the flagship project The Global Commission on the Economy and Climate. The report that was delivered to the UNGA in Sep 2014 provides independent and authoritative evidence on the relationship between actions which can strengthen economic performance and those which reduce the risk of dangerous climate change. The Global Commission on the Economy and Climate is a major international initiative to analyse and communicate the economic benefits and costs of acting on climate change. Chaired by former President of Mexico Felipe Calderón, the Commission comprises former heads of government and finance ministers and leaders in the fields of economics and business.

- *Limited investments* – Global developments are constrained by limited investments in new infrastructure.
- *Well-developed infrastructure* – Infrastructure is well developed as a result of good access to public and / or private investment finance, but these investments are not necessarily green or low-carbon infrastructure investments.

Energy system: The structure of energy systems regarding availability and share of fossil sources.

- *Clean electricity* – Emissions free electricity is the dominating source and carrier of energy. It is generated in ample supply in both centralised and decentralised systems.
- *Uncertain availability, high volatility* – Energy supply is uncertain and prices volatile. Well-endowed countries and regions have comparative advantage.
- *Electricity and fossil* – Energy supply is stable with electricity playing a dominating role as energy carrier based on both fossil and renewable sources.

Energy cost share of GDP: The share of GDP that is needed to provide energy. A higher energy cost share of GDP implies that less financial resources are left over for other needs, e.g. higher education, culture, advanced health care, infrastructure developments, etc.

- *Low* – Energy is relatively affordable in relation to GDP leaving plenty of options for other developments.
- *Medium* – Energy constitutes a substantial cost both in terms of public and private finance but there is still economic space for other developments. This drives energy savings and limits the use of energy intensive practices
- *High* – The cost to provide for energy is so high that it affects society at large, limiting options for other developments. Energy intensive practices are used only for very special needs to produce highly valuable products.

ENVIRONMENT AND ENVIRONMENTAL POLICY

Resource efficiency: The efficiency by which resources is used is estimated qualitative here in terms of the degree of a circular economy (i.e. to what degree resources including waste are recycled in the economic system[3]

- *Leaky circular* – Circular economic practices are prevailing but some sector or regions have not managed to set up systems and procedures for recycling resources in an effective way.

[3] Wikipedia defines a circular economy as generic term for an industrial economy that is, by design or intention, restorative and in which material flows are of two types, biological nutrients, designed to re-enter the biosphere safely, and technical nutrients, which are designed to circulate at high quality without entering the biosphere. See https://en.wikipedia.org/wiki/Circular_economy

- *No circular economy* – Resources are used in a wasteful way and recycled only to a limited degree.

Climate policy: The extent to which global or international climate policy arrangements exist.

- *Top down climate framework* – A climate framework has been agreed between a majority of the countries in the world.
- *No climate agreement* – There is no global agreement, but individual countries could still take unilateral action.
- *Coalitions of Willing* – A limited number of countries have decided to take joint action by e.g. agreeing on goals, setting sectoral standards and trade rules.

Environmental governance: The degree of strength and coordination of environmental governance.

- *Strong* – Strong and well-coordinated environmental governance systems, either through global or regional agreements, are influential in shaping global behaviours.
- *Lax* – Environmental governance plays a limited role in shaping behaviour.

Environment and climate status: The degree of climate and environmental impacts from low-end to high-end, referring to the range of uncertainty expressed by scientific forecasts.

- *Low-end* – Environmental and climate impacts follows a low trajectory with temperature increases stabilising under 2 degrees warming, and only limited climate and environmental related catastrophic impacts.
- *High-end* – Environmental and climate impacts escalates with global warming beyond 2 degrees heading towards 4 degrees warming by 2100. Environment and climate related impacts with catastrophic regional and global effects are prevalent and have serious social and economic effects.

BUSINESS AND TECHNOLOGY

Business models: The models that business uses to charge for their production.

- *Product* – Businesses generate profit mainly through the process of manufacturing and selling products (including the whole product chain from extraction, through manufacturing, transportation and retailing).
- *Function* – Businesses make profit mainly by using knowledge and products (manufactured in-house or by other firms) to charge for the use of a function, e.g. rental, occupancy or functionality.

Innovation, IPR and digitalisation: How ideas and technologies are distributed.

- *Free open access* – Ideas and technologies are accessible through well-functioning, effective digital systems for sharing of intellectual property.

- *Big corps and states* – A substantial share of new ideas and technologies are owned and kept by big corporations and states and are seen as strategic assets that are not readily available.

2.2 The scenario framework

The combination of states presented above could theoretically generate over 700,000 scenarios that could be combined into 10^{22} different sets of four scenarios. The cross impact balance analysis narrowed down the number of fully consistent scenarios to 17. The scenario diversity analysis showed that a limited number of these combinations represented a set of four scenarios that spanned the array of possible futures effectively. The set of four scenarios that was finally selected is presented in Table 2 below. These combinations of drivers and states constitute the 'seeds' or 'scaffolding' for each of the scenarios, upon which the scenario narratives have been developed. The scenario narratives are presented in section 3 below.

2.3 The indicator set

An indicator set was developed to illustrate in quantitative terms how key quantitative indicators could develop under each of the scenarios. The indicator set has also been used to enhance comparability between the scenarios. The indicator set is based on the Kaya identity[4], which relates fundamental human activities to emissions of carbon emissions.

The Kaya identity is derived from the simpler, and more general, IPAT identity which relates environmental impacts to the three factors P = population, A = affluence and T = technology: I = P*A*T. Hence, *ceteris paribus*, increases in e.g. population will tend to increase environmental impacts. In the Kaya identity the impacts is specified as emissions of carbon dioxide and technology is broken down into energy efficiency (the amount of energy used for each unit of GDP) and carbon dioxide intensity (the amount of carbon dioxide emitted for each unit of energy):

The indicators were assessed by the scenarios team on the basis of a range of available forecasts. The indicators for each of the scenarios is presented with the narratives in section 3 below.

A summary of each Kaya indicator across all scenarios is presented in section 4. The charts for GDP per capita, population growth and carbon emissions have been

[4] The Kaya identity has been widely used in different scenarios and forecasting exercises, e.g. in the International Panel on Climate Change's (IPCC) Special Report on Emission Scenarios. See more in Kaya, Y. (1990) "Impact of carbon dioxide emission control on GDP growth: interpretation of proposed scenarios", paper presented to IPCC energy and Industry sub-group."

complimented by benchmark indicators derived from the Shared Socioeconomic Pathways (SSP) database. The SSPs are part of a new framework that the climate change research community has adopted to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation[5].

On the basis of the SSP database a calculation of highest and lowest estimates for GDP growth (purchasing power parity) has been calculated to provide reference to the economic growth rates in the scenarios in this report and SSP scenarios by OECD. See Table 1 below.

	Scenario 1: Transatlantic green consensus	Scenario 2: Global scramble	Scenario 3: Autobahn	Scenario 4: High-tech hamlets	SSP5 (OECD) lowest	SSP3 (OECD) highest
2010-20	2.5%	2.3%	3.0%	2.0%	4.1%	4.3%
2020-30	1.4%	2.0%	3.3%	1.7%	2.9%	5.0%
2030-40	1.8%	1.5%	2.6%	1.3%	1.7%	4.5%
2040-50	2.2%	1.5%	1.9%	1.0%	1.2%	3.4%

Table 1: Annual GDP growth rates per decade, comparison between scenarios in this report and SSD scenarios by OECD

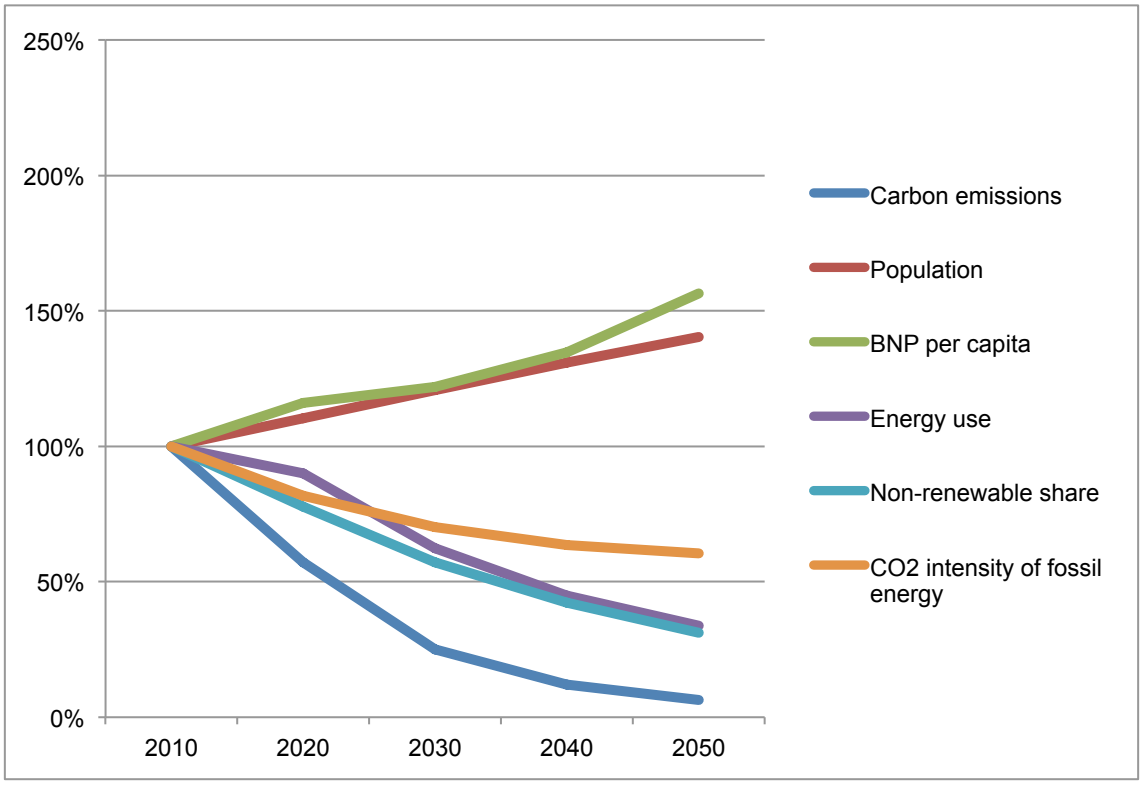
[5] See further at https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about

	1: Transatlantic green consensus	2: Global scramble	3: Autobahn	4: High-tech hamlets
GLOBAL POLITICAL ECONOMY CONTEXT:				
Global power structures	Transatlantic leadership	Global disorder	Globalised without borders	Multipolar
Economic governance	Government driven	Fragmented	Market driven	Decentralised polycentric
International trade	Green trade	Fragmented trade	Open global trade	Fragmented trade
SOCIAL STRUCTURES AND URBANISATION:				
Wealth distribution	Large global middle class	Stagnated global middle class	Large global middle class	Stagnated global middle class
Urbanisation	Medium	High	High	Low
ENERGY AND INFRASTRUCTURES:				
Infrastructure	New Climate Economy	Limited investments	Well-developed infrastructure	New Climate Economy
Energy system	Clean electricity	Uncertain availability high volatility	Electricity and fossil	Clean electricity
Energy cost share of GDP	Low energy cost share	Medium energy cost share	Medium energy cost share	High energy cost share
ENVIRONMENT AND ENVIRONMENTAL POLICY:				
Resource efficiency	Leaky circular	No circular economy	Leaky circular	Leaky circular
Climate policy	Top down framework	No climate agreement	Coalitions of Willing	Coalitions of Willing
Environmental governance	Strong	Lax	Lax	Lax
Environment and climate status	Low-end	High-end	High-end	Low-end
BUSINESS AND TECHNOLOGY:				
Business models	Function	Product	Function	Product
Innovation, IPR and digitalisation	Free open access	Big corps and states	Free open access	Free open access

Table 2: Drivers and states for each of the scenarios

3 Scenario narratives

3.1 Scenario 1: "Transatlantic green consensus"



Status by 2050

- A revival of an inclusive transatlantic cooperation has driven a successful low-carbon development, where technology cooperation has come in the forefront of an inclusive Transatlantic Trade and Investment Partnership (TTIP) [6].
- Government sponsored public private partnerships laid the ground for a shift to largely decentralised electricity based energy systems that played a key role in facilitating this changeover.
- At the same time value creation has gradually been driven by function rather than product, which has led to a leapfrogging in energy and resources efficiencies.
- As a result the service sector has grown to become an important driver of wealth creation, at the same time as most societies use only a small share of their economic wealth to provide for energy needs.

[6] The Transatlantic Trade and Investment Partnership (TTIP) is a free trade agreement between the European Union and the United States that is currently being negotiated. If successful, it could have considerable impacts on trade and economic cooperation between the parties. But it could also come to have negative influences in terms of e.g. environmental standards.

- Strong emphasis on keeping open access to data as well as intellectual property has enabled proliferation of new low-carbon processes and products in developed as well as developing countries. The provision of certain important technologies through open access systems is partly driven by business interests to benefit from bigger market opportunities (ref Tesla battery technology).
- New modes of energy efficient transport, including new modes of hyper efficient sea- and airfreight has kept costs of transport rather low, but still considerably higher than in the early part of the century. However, the higher costs have been offset by products being much less materials intensive at the same time as more sophisticated global production systems including 3D printing has reduced the need to ship components across the world.
- As fossil based energy has largely been phased out the world has succeeded in establishing a global economy without net carbon emissions, and the global average temperature increase has been keep below 2 degrees.
- This has generated a positive income development with increasing wellbeing on a global scale. Initially, however, the economic engine was developed in the TTIP countries, which led to growing global income disparities.

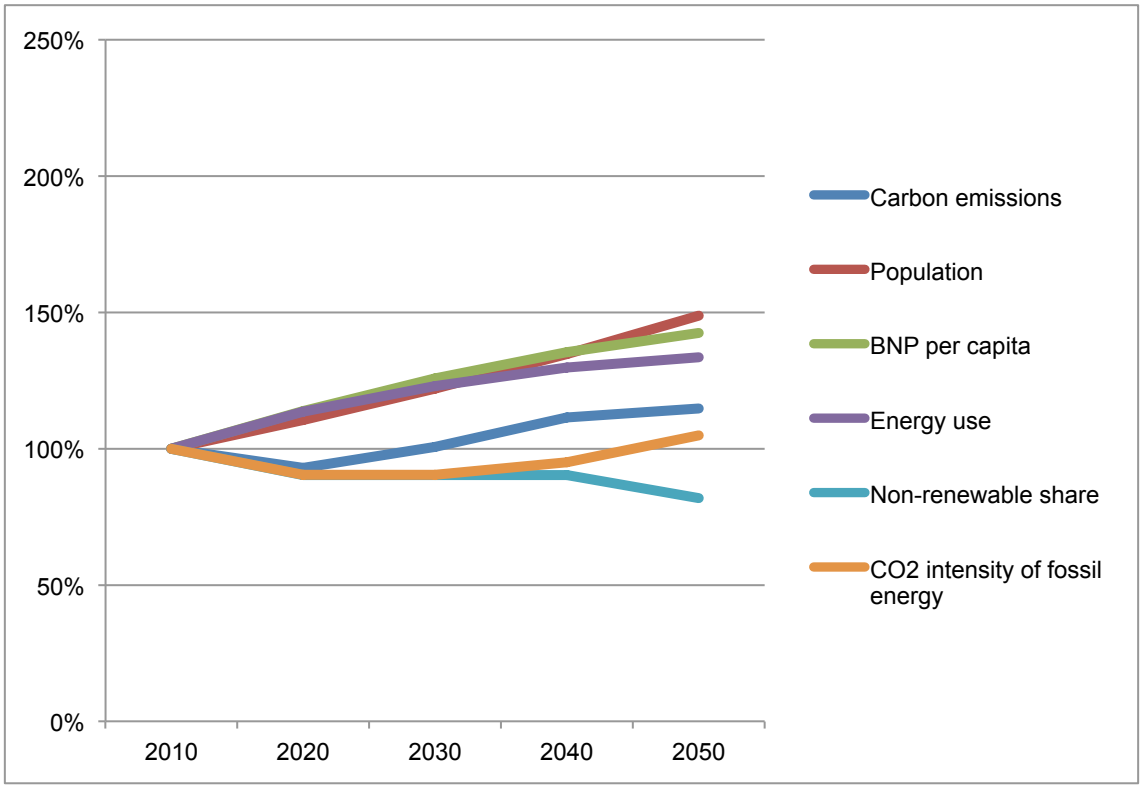
How did we get here?

- Toward the end of the 2010s the TTIP managed to establish a reinvigoration of the transatlantic cooperation. At the same time there was considerable difficulties to make the Trans-Pacific Partnership (TPP) work. China's economy slowed down considerably and Russia failed to revive its fossil dependent economy. As a consequence focus in international trade and investments shifted away from Asia towards the transatlantic region.
- In the 2020s the role of the WTO diminished further. Instead the North American Free Trade Agreement (NAFTA) linked up with the TTIP and provided a common platform for trade and investment cooperation that covered a considerable share of the global economy. Several of the governments in the TTIP-NAFTA region saw opportunities and multiple benefits in low-carbon investment, and a compact of leading countries moved ahead to create a transatlantic low-carbon trade zone. At the same time green bonds and other new and innovative green financing mechanisms begun channelling considerable capital to low-carbon investments. As a result of the emerging shift towards low-carbon technologies the UNFCCC managed by the end of the decade to bring together an agreement that lay the ground for an effective transfer of technologies to LDCs.
- In the early 2030s an ambitious charter was signed between leading emitters that effectively managed to control two-thirds of total emissions,

which further spured productivity driven economic development and wealth creation.

- In the 2030-40s onward the new low-carbon infrastructure provided a foundation for more productivity driven development and new business models focusing on function rather than product.

3.2 Scenario 2: "Global scramble"



Status by 2050

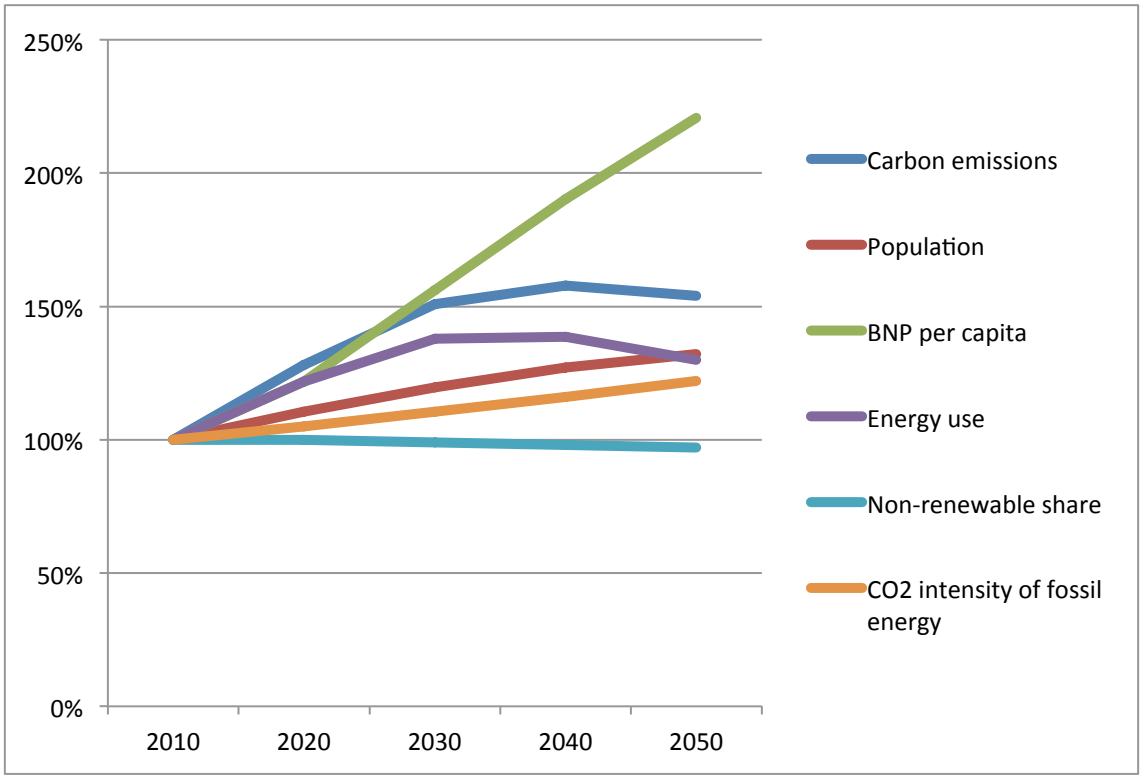
- Global governance has eroded and created a situation where nation states and other actors compete to control the resources they needed.
- A mosaic of nations and economic interests characterises the global order, with no single actor in supreme power.
- While some regions fare better than others there is a generally low economic development, as comparative benefits cannot be fully utilised in a fragmented trade system.
- Trade is limited compared to the globalised world of the 2010s and prices vary as a result of different access to energy in different parts of the world.
- Global investment levels are generally low but stronger and richer actors build what they like.
- Lack of opportunities in countryside has driven large-scale urbanisation, but quality of urban areas is generally poor.
- Lack of investments lead to volatile energy prices but regional differences are large with well-endowed regions enjoying affordable energy as they grab what is the cheapest. But supply scarcities have increased both volatilities and prices over time. In some countries without local energy sources alternative energy has been developed, but at a higher cost due to lack of global cooperation.

- In this fragmented world there are huge social, economic and political differences, with large parts of the world struggling with poverty.
- Although the lower economic activity and disconnected world has led to a slowdown of emissions, the unchecked use of fossil energy in well-endowed regions has kept emissions too high to keep the world on a 2-degree trajectory.
- Increasingly severe climate and environmentally related catastrophes (droughts, chemical accidents, typhoons, heat waves, etc.) have increasingly severe impacts around the world.

How did we get here?

- Towards the late 2010s and early 2020s the global governance failed to provide united leadership. This downward spiral was largely driven by an increasingly assertive but poorer Russia and a Chinese leadership that began driving an aggressive investment led expansion in particularly South-East and Central Asia and in Africa in order to overcome the effects of a stagnating domestic economy.
- In the 2020s the US became more inward looking due to self-dependency on energy including abundant fossil supplies. The EU began breaking up as Greece's leaving the EMU was followed by the UK leaving the union.
- By 2030 the global governance had become effectively defunct with the UN Security Council no longer operational and WTO entirely marginalised.
- During the 2030s new patterns of ad hoc coalitions appeared as countries and other actors tried to secure vital interests.
- In the 2040-ies some regions with less access to the increasingly scarce and expensive oil and gas, and also due to the increasing difficulties to trade, have to turn either to renewables or to coal, leading to both a lower share of non-renewable energy and to a higher carbon intensity of the remaining fossil fuel use.

3.3 Scenario 3: ”Autobahn”



Status by 2050

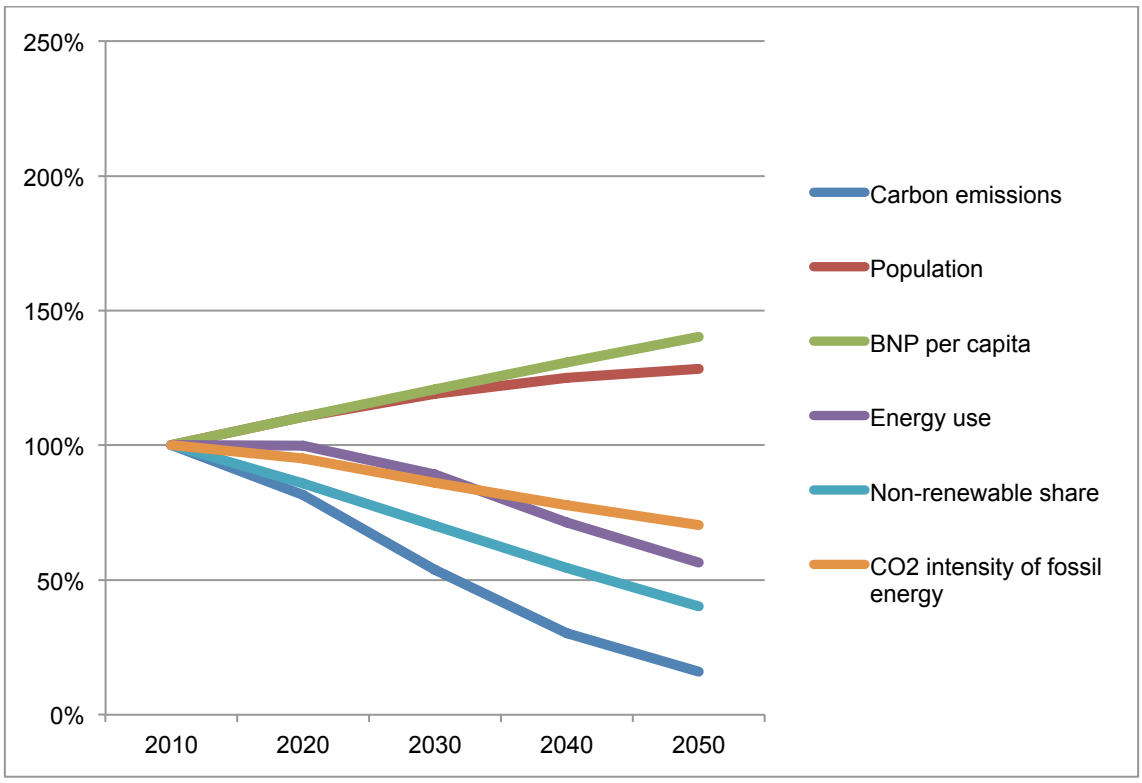
- Unconstrained globalisation driven by comparative advantage in a market driven world has generated a strong global economy.
- Economic growth has reduced poverty and boosted a large global middle class, which consumes and maintains a high material metabolism requiring huge amounts of resources.
- Still, living conditions differ widely between countries and regions, particularly as a result of growing climate and environmental impacts.
- There is a mix of business models, whichever makes more sense economically at the global market and attracts the large global middle class.
- High investment levels has delivered well-developed infrastructure, particularly in the growing urban centres. Both fossil and clean energy come at a fairly high cost share of GDP, due to the high total demand, which take toll at the supplies and keep prices up. Fossil is still widely used where it makes economic sense.
- Higher energy prices have affected trade with decreasing total volumes, while better efficiencies in the trade system has kept up the value of trade.
- Coalitions of richer countries with good access to technology have agreed to reduce emissions, but these reductions have been limited to what have been seen as risk-free from an economic point of view.

- As ecosystems are only of concern when adding monetary value, short-term economic interests have been the sole driver of any green developments in technology, energy systems and materials. Technology development and productivity have mitigated some carbon dioxide and other environmental emissions, but far from enough to keep up with the growing overall ecological footprint of the world economy.
- Consequently, the world is on a trajectory beyond two degrees temperature rise, which has been reflected by increasingly severe climate and environmentally related catastrophes (droughts, chemical accidents, typhoons, heat waves, etc.). As a result of this, and of resources getting scarcer and more expensive, it has become increasingly difficult to maintain economic growth.

How did we get here?

- As several of the regional and bilateral trade agreements had managed to unlock some of the difficulties that had stalled the Doha round, WTO got a renewed mandated. This precipitated a new and much more successful "Development round" of WTO based trade agreements.
- Europe succeeded in resolving some of its financial problems, but at high social and economic costs. North America found itself self-sufficient in energy supply the US became less concerned with patrolling the high seas. With a growing share of trade and investment the world's economic focus shifted towards Asia-Pacific.
- Through the 2020s a peaceful development combined with rising demand from growing middle classes and comparative advantage created an industrial and economic boom in Africa.
- Gradually in the 2020s and 2030s big, transnational companies come to play more important role in shaping global governance. Forums like Davos become agenda setting while G20 and similar nation state based meetings become arenas to bicker about and settle on the political support. The WTO grew increasingly powerful as the executing agency for global free trade.
- From the 2030s there were increasingly serious cases of regions where ecosystems became degraded to an extent that had considerably negative effect on the economy. This did not affect the global economy as long as production could be moved and new substitute materials made up for lost supply. A gradual shift towards services and new business models offering function rather than products did also help to make up for environmental degradation.
- From the 2040s the environmental limits have begun having more serious systemic effects on the global economy, with several very serious climate related catastrophes.

3.4 Scenario 4:
"High-tech hamlets"



Status by 2050

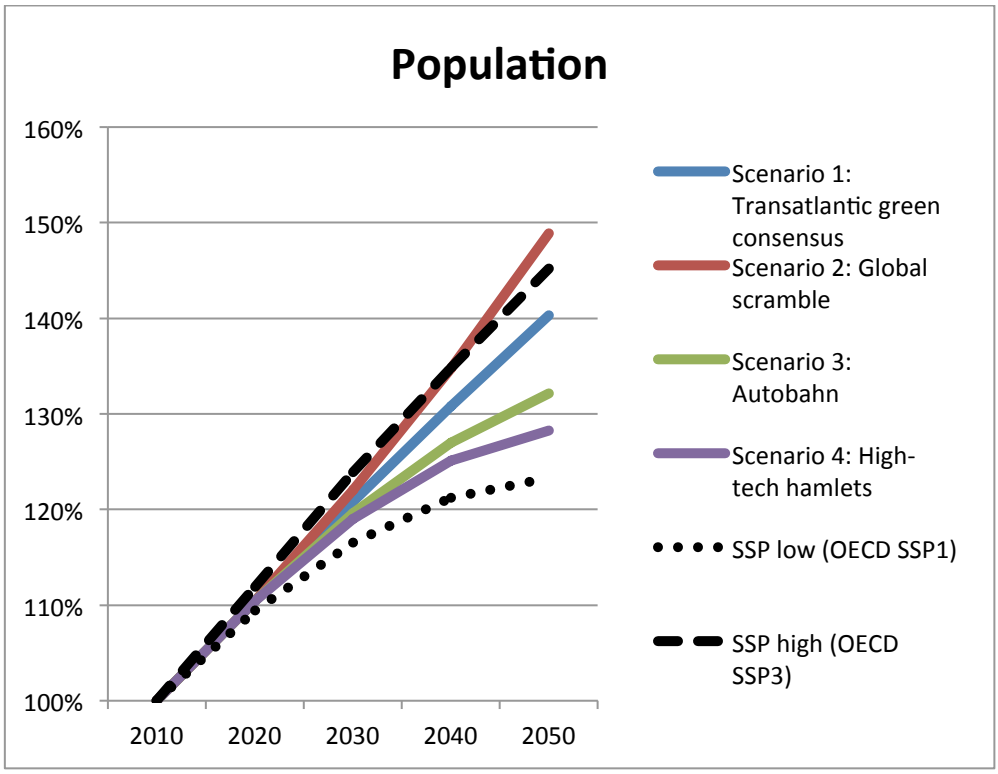
- Fragmentation of global trade – driven by high costs of transport and growing trade barriers, but also by stronger support for sustainability and preferences to ensure local livelihoods in the face of climate and environmental threats – have propelled a diverse world with a variety of choices for development pathways.
- The multitude of market arrangements, legal communities and political systems has created a multipolar global system, where fragmentation is less a result of failure to cooperate than it is a response to a perceived need for regional and local solutions to sustainable development that are adapted to regional preferences and conditions.
- With less globalised trade patterns the global economy has grown by a third (on a per capita basis) compared to 2010 levels, less than in other scenarios
- As the transitional change moreover has required considerable investments in low-carbon energy infrastructure, a large share of GDP is still required to cover energy costs.
- The global growth of middle classes has stagnated. In particular, regions that suffer the climatic and environmental impacts from previous emissions, or those that cannot compete in the new trade patterns are struggling economically. Many parts of the world have seen poverty prevailing, although the number living in absolute poverty has decreased.

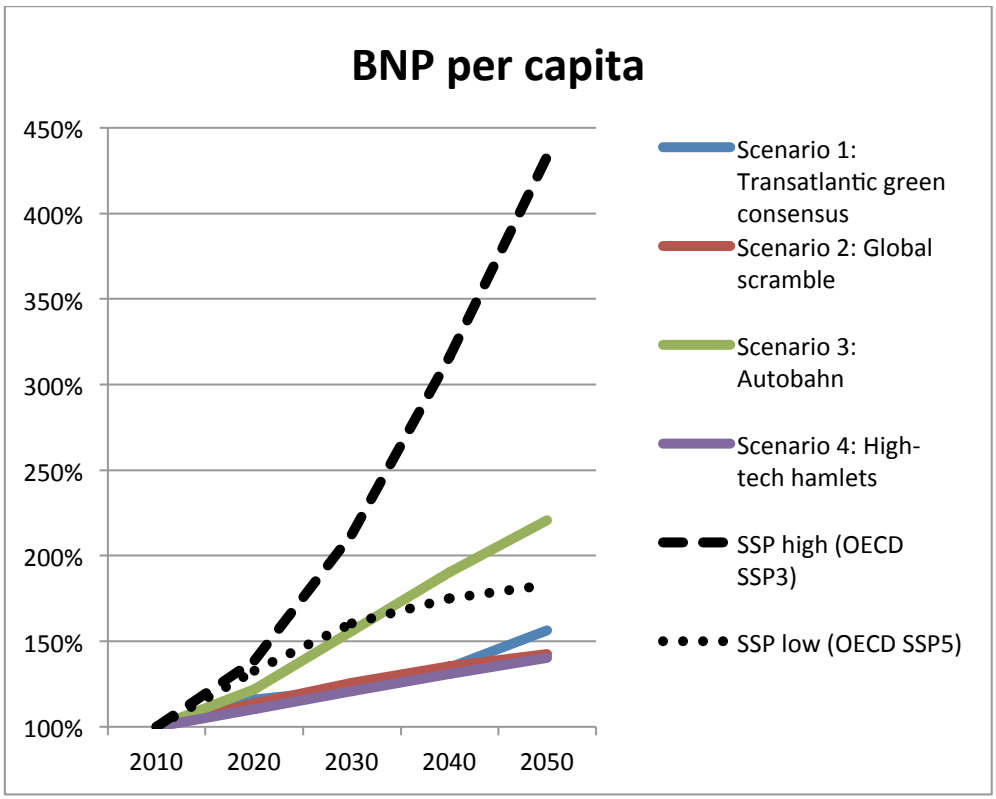
- While trade is predominantly regionalised there is considerable global exchange and interaction with regards to knowledge, information, culture and ideas.
- Although local societies have grown stronger, the provision of some public or global common goods still requires international regimes and global governance structures exist but are not very strong. In terms of climate mitigation a coalition of the willing has emerged in a bottom-up process through increasingly ambitious pledges.
- With high energy cost share and small markets business models remain product oriented despite data and technologies being accessible.
- While different examples of circular economies exists around the world some regions still rely on material endowments that cause wasteful behaviour.
- The reverse of globalisation, considerable reductions in global trade, and slower economic performance in combination with considerable progress in local and mostly decentralised low-carbon energy systems, has reduced carbon considerably and the world has reached zero net emissions. As a result the global average temperature increase has been limited to 1.5 degrees.

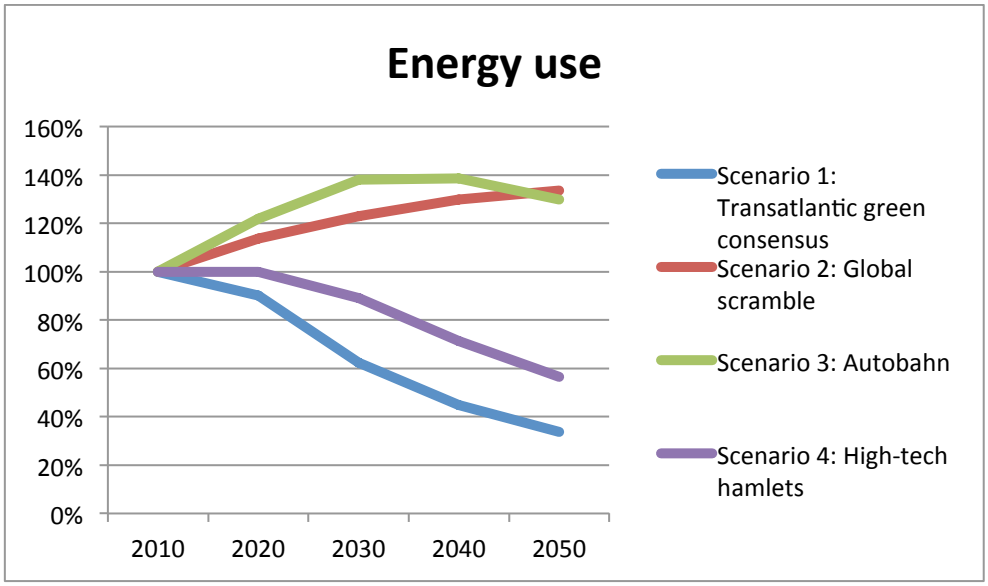
How did we get here?

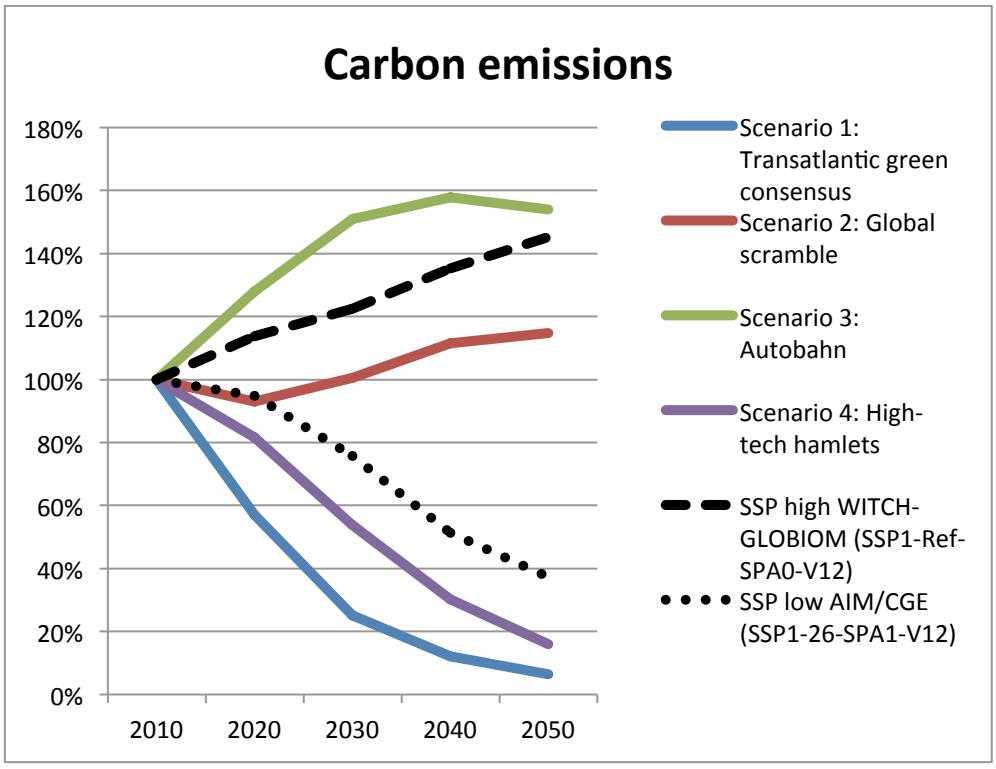
- In the late 2010s and early 2020s global economic growth stagnated with reappearing episodes of recession in many developed economies and rapidly declining growth in former so called emerging economies. This caused trade tensions and subsequent volatilities on oil and energy markets.
- As energy bills in many energy import dependent countries began taking an increasingly bigger share of the economies there was an increasing focus on local solutions including efficiencies.
- Through the 2020s there was also a growing feeling of urgency to address increasingly violent climate and environmental threats. This lead to a strong realisation around the world that resource choices and technology options that are adapted to regional and local conditions have wider local benefits and that these are a prerequisite for continuous well-being.
- In the 2030s this combination of partly self-imposed austerity and ideological shifts continued to drive considerable reductions in energy use and carbon dioxide emissions.
- in the 2040-ies the slowly increasing affluence and the awareness of increasing resource scarcities more and more countries follow the trend from earlier decades with lower nativity, making population increasing even more slowly.

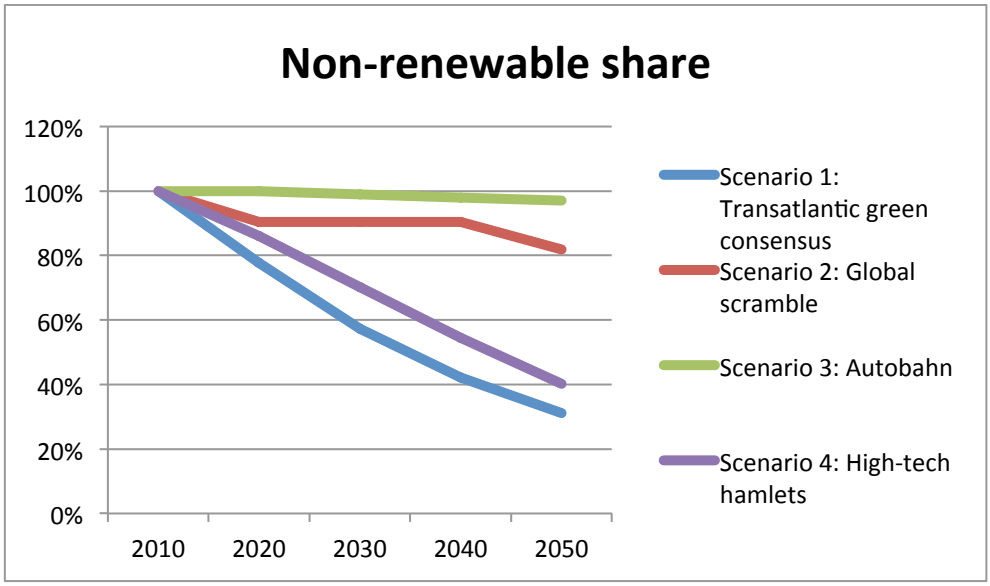
4 Summary of each Kaya indicator across all scenarios

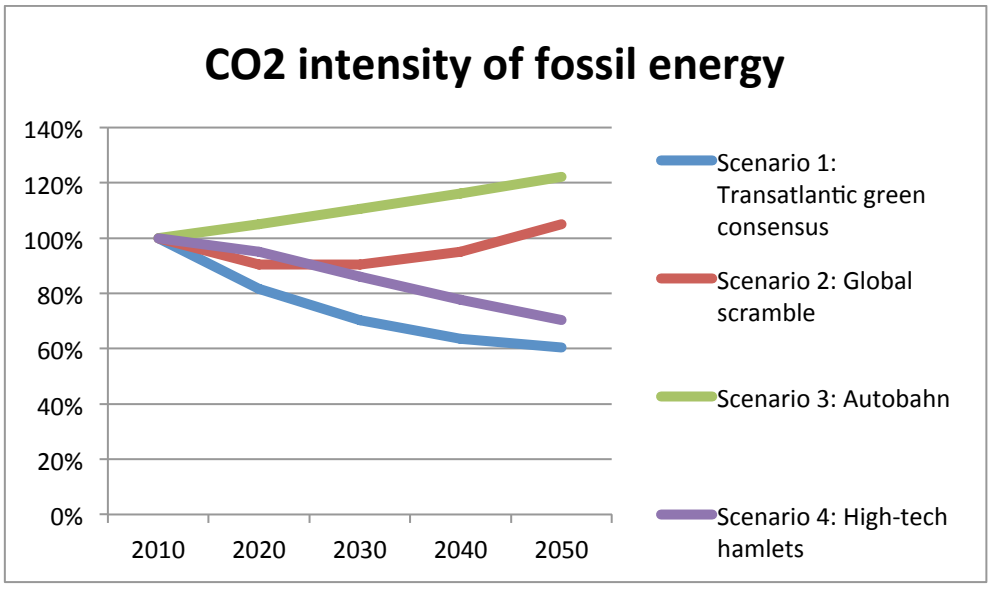





Energy use
160%
140%
120%
100%
80%
60%
40%
20%
0%
2010
2020
2030
2040
2050
Scenario 1: Transatlantic green consensus
Scenario 2: Global scramble
Scenario 3: Autobahn
Scenario 4: High-tech hamlets


Carbon emissions
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
2010
2020
2030
2040
2050
Scenario 1: Transatlantic green consensus
Scenario 2: Global scramble
Scenario 3: Autobahn
Scenario 4: High-tech hamlets
SSP high WITCH-GLOBIOM (SSP1-Ref-SPA0-V12)
SSP low AIM/CGE (SSP1-26-SPA1-V12)


Non-renewable share
120%
100%
80%
60%
40%
20%
0%
2010
2020
2030
2040
2050
Scenario 1: Transatlantic green consensus
Scenario 2: Global scramble
Scenario 3: Autobahn
Scenario 4: High-tech hamlets


CO2 intensity of fossil energy
140%
120%
100%
80%
60%
40%
20%
0%
2010
2020
2030
2040
2050
Scenario 1: Transatlantic green consensus
Scenario 2: Global scramble
Scenario 3: Autobahn
Scenario 4: High-tech hamlets

Appendix A: Methodology for constructing scenarios

The construction of the scenario set was based on the results from the first workshop. In order to strengthen the quality of the product of this stage of the project, i.e. the scenarios, and to enhance transparency of the process, two different quantitative techniques were employed for constructing the scenarios. This appendix describes this process.

Scenarios can be constructed in many different ways. This project applies morphological analysis based approach, where scenarios are expressed by means of *drivers* and associated *states*. Each driver is a discrete variable that can take a finite number (usually 2-5) of mutually exclusive states. A discrete variable can be *ordinal* or *nominal*. The states of an ordinal variable can be ordered in a meaningful way, e.g. the states of the variable GDP growth could quite naturally be ordered High > Medium > Low. The states of a nominal variable, however, cannot be ordered in relation to one another.

A scenario is then defined as one state for each variable, as illustrated in Table 3.

Driver A	Driver B	Driver C	Driver D
State A1	State B1	State C1	State C1
State A2	State B2	State C2	State C2
State A3	State B3		State C3

Table 3: Drivers, states and one scenario. All drivers except Driver C have three possible states each. The shaded cells represent a scenario. In this table, there are 54 possible scenarios (3*2*3*3). In practice, the set of possible scenarios is limited by the fact that there are impossible or implausible combinations of states.

Given that this 'morphological field' makes it possible to construct more than 700,000 different scenarios, the question arises how a 'good' scenario set of say four scenarios can be chosen. We first note that this choice can be made in an enormous number of ways. With 700,000 scenarios, sets with four scenarios can be chosen in 10^{22} different ways.

There are a myriad of answers to this rather open question, but as a rule of thumb it is often said that the scenarios developed for a client or for a specific problem should be: a) relevant, b) plausible, and c) representative.

That the scenarios should be plausible goes without saying. The scenarios need to describe the development in the external world that are relevant to the question under study. This aspect of scenario development is secured via a participatory approach including a well-defined focus question (see workshop 1 report).

Plausibility is related to the nearby concept of probability. It is a key characteristic of the scenario approach employed here that the scenarios are *not* forecasts; no probabilities are assigned to the individual scenarios. Yet, each of the scenarios should be 'logically consistent' so that the story holds together and provide the scenario user with a sound description of a plausible future. Relevance and plausibility are properties that should be fulfilled by *each* scenario in a set. In contrast, representativeness is a property of *sets* of scenarios. That is, the set, e.g. four scenarios, should as far as possible represent an array of plausible futures. It is important to stress that this does not mean that the future development must follow any of these four scenarios, but rather that the scenarios as a whole should span the space of what is imaginable.

A methodology called *Cross-Impact Balance* (CIB) was employed in order to operationalize the idea of plausibility. With the variables and states as defined in 2.1 Drivers and states in the main text above, a cross-impact matrix was constructed. For each state of each variable an assessment of the impact of that state on other states for other variables were made. The following scale was used:

+3: Strongly promoting influence
+2: Moderately promoting influence
+1: Weakly promoting influence
0: No influence
-1: Weakly restricting influence
-2: Moderately restricting influence
-3: Strongly restricting influence

An example for two variables is given below in Table 4.

Table 4. An example of the assessment of cross-impacts between the states of two drivers

	A		B			
	A1	A2	B1	B2	B3	B4
A. Environmental and climate status:						
A1: High-end			2	-1	-1	0
A2: Low-end			1	0	1	-2
B. Global power structures:						
B1: Global disorder	1	-1				
B2: Stable but polarised	1	-1				
B3: Transatlantic leadership	1	-1				
B4: Globalised without borders	0	0				

In this way, all possible combinations of states for all 14 drivers were assessed. The complete cross-impact matrix can be obtained on request.

With the complete cross-impacts matrix as a basis, *perfectly consistent scenarios* were generated. In such a scenario, every state is chosen in such a way that no other state of the same variable is more strongly preferred by the combined influence of the other variables. The inconsistency score for a scenario is defined as the maximum difference between the impact balance score of the given state and all possible states that can be found across all variables. The inconsistency score is always 0 for perfectly consistent scenarios since the choice of states is optimal.

This analysis generated 17 fully consistent scenarios out of the more than 700,000 possible scenarios. Selecting 4 scenarios 17 can only be done in 2,380 different ways, hence considerable less than 10^{22}.

As the cross impact analysis focuses on consistency it does not ensure that the most consistent scenarios are very different from one another. Consequently, they are not necessarily representative of a wider range of alternative futures developments. Therefore, in order to represent as broad as possible an array of possible futures a second quantitative scenario technique – *Scenario Diversity Analysis* (SDA) – was used. SDA employs a measure of distance between pairs of scenarios, defined so that the distance is large when the distances between the states for each scenario variable are large, and the sum of all distances for each state is defined as the distance between two scenarios. A numerical optimisation algorithm uses this distance measure to find a set of scenarios that maximizes the sum of all distances between the scenarios.

As an example consider the scenario in Table 3 above, (A1, B1, C2, D1). Let us call this scenario 1, S_1. With a second scenario S_2 defined as (A1, B2, C1, D2), the distance between those two scenarios is defined as $D(S_1, S_2) = 0 + 0.5 + 1 + 0.5 = 2$. Each of the distances in this metric is defined on the interval [0,1]. For the first driver (A), the same state is assumed in the two scenarios; hence the distance is 0 here. For the second driver, nearby states are assumed, hence the distance is 0.5. For the third driver there are only two states and here we assign distance = 1 if the states are different and 0 if the states are the same.

With these measures, a distance matrix showing all the distances between pairs of the 17 most consistent scenarios can be calculated, see Table 5.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	7,5															
3	6,5	1														
4	2,5	10	9													
5	9,5	12	12	7												
6	0,5	8	7	3	10											
7	7	1,5	0,5	9,5	12,5	6,5										
8	2,5	8	7	3	9	2	6,5									
9	4	9,5	8,5	1,5	7,5	3,5	8	1,5								
10	3	10,5	9,5	0,5	7,5	2,5	9	2,5	1							
11	10	12,5	12,5	7,5	0,5	9,5	12	8,5	7	7						
12	1,5	8	7	4	10	1	6,5	2	3,5	3,5	9,5					
13	7,5	2	1	10	13	7	0,5	7	8,5	9,5	12,5	7				
14	3	8,5	7,5	3,5	9,5	2,5	7	0,5	2	3	9	2,5	6,5			
15	9	8,5	7,5	9,5	9,5	8,5	7	9,5	9	9	9	7,5	6,5	9		
16	11,5	13	13	9	2	11	12,5	10	8,5	8,5	1,5	11	12	9,5	7,5	
17	7,5	13	13	5	4	7	12,5	6	4,5	4,5	3,5	7	12	5,5	9,5	4

Table 5. The distance between all pairs of scenarios

The mean distances vary between 0,5 and 13. Given this matrix the task is to select four scenarios that maximises the internal distances between all scenarios in the set. Two measures are of relevance: the minimum distance between any pair in the set of four scenarios, and the mean distance of all distances between the four scenarios (i.e. 6 distances). In this analysis we only focused on maximizing the mean distance; it turned out that this optimal result given this condition also produces sets with a high value of the minimum distance.

Figure 2 below shows the distribution of the mean distances for all possible 2,380 sets.

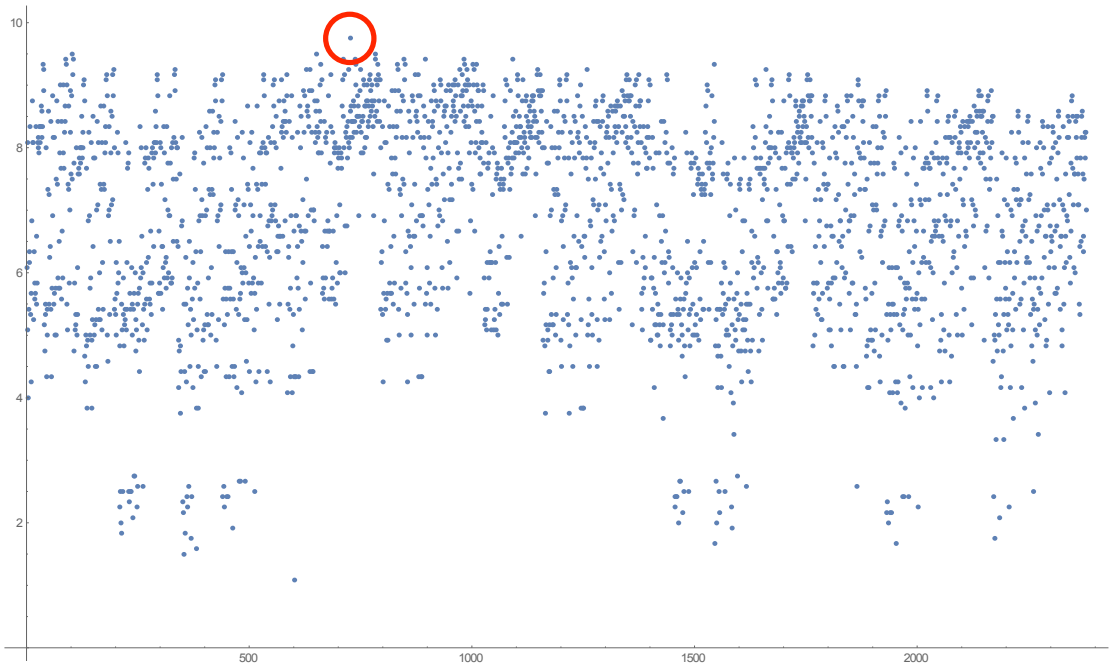


Figure 2: Distribution of mean distance for all scenario sets

The analysis showed that there is a unique set with maximum value of mean distances between all scenarios (inside the red circle), D = 9,75. Of course one cannot blindly follow the quantitative analysis and select this set; the selection must also be informed by a qualitative assessment of the four scenarios in this set. When analysing sets at the upper range over the diversity spectrum a set with a still very high diversity (D = 9,1) was finally selected. This set is shown in Table 2 in the main part of this report. This is the final result of the quantitative analysis.