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# An integrated three-layered foresight framework

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## Abstract

**Purpose** – *The paper aims to present an integrated foresight framework and method to support decision-makers who are confronted with today's complex and rapidly changing world. The method aims at reducing the degree of uncertainty by addressing the inertia or duration of unfolding trends and by placing individual trends in a broader context.*

**Design/methodology/approach** – *The paper presents a three-layered framework and method for assessing megatrends based on their inertia or duration. It suggests that if long-term trends and key future uncertainties are studied in conjunction at a meta-level and placed in a broader multi-layered framework of trends, it can result in new insights.*

**Findings** – *The application of the proposed foresight method helps to systematically place a wide range of unrelated trends and key uncertainties in the context of a broader framework of trends, thereby improving the ability to understand the inertia, direction and mutual interaction of these trends.*

**Research limitations/implications** – *The elaboration of identified trends and key uncertainties is partly case-specific and subject to interpretation. It is aimed at illustrating the potential use of the framework.*

**Practical implications** – *The paper presents a new approach that may, by itself or in combination with existing foresight methods, offer new means for anticipating future developments.*

**Social implications** – *The use of the proposed framework has potential to provide better insight in the complexity of today's rapid-changing world and the major transitions taking place. It aims to result in sharper foresight by reducing epistemic uncertainty for decision-makers.*

**Originality/value** – *The paper demonstrates how megatrends, Kondratieff waves and century-long trends can be placed in an integrated framework and analysed in conjunction.*

**Keywords** *Uncertainty, Foresight, Decision-making, Kondratieff, Megatrends*

**Paper type** *Research paper*

## 1. Introduction

In today's complex rapid-changing world, trends in various spheres interact in increasingly unpredictable ways so that a single-issue focus is no longer sufficient to deal with emerging threats and opportunities ([Habegger, 2010](#); [UNDP GCPSE, 2014](#)). The objective of strategic foresight is to take what we know and project it forward in useful ways ([Wayland, 2015](#)). Foresight practitioners are challenged to improve insight into plausible futures by a systematic process of anticipation ([Martin, 1995](#)). Plausible developments can be described by means of trends and key uncertainties. Trends describe historical changes up until the present, which can be expected to continue until they bend or break. Key uncertainties relate to emerging developments, which play a role in bending or breaking historical trends such as a possible new technology, a potential public policy issue or a concept, and can develop into a trend in its own right ([Lum, 2016](#)).

The expectation of what foresight is able to tell about future developments is influenced by outspoken perceptions of rapid or even exponential change, such as discussed in work of futurists such as [Brynjolfsson \(2014\)](#) and [Leonhard \(2016\)](#) and in literature in the Futures field on "postnormal times" ([Sardar, 2010](#); [Sardar and Sweeney, 2016](#)). Awareness of rapid

change is also evident in the mindset of decision-makers and policy advisors, as reflected in the extensive literature on methods for dealing with wickedness and deep uncertainty (Walker *et al.*, 2013).

In spite of these views, we argue that not all future developments are equally uncertain. The perceived degree of uncertainty relates to the inertia (or duration) of unfolding trends and our understanding of the broader context in which they take place. This paper proposes an integrated three-layered framework, which represents the first step in a theoretical method for assessing megatrends based on their inertia and mutual interaction and illustrates the application of the method for a practical case study for the Port of Rotterdam. The framework suggests that by systematically analysing well-known trends and key future uncertainties in conjunction at an overarching meta-level, and by placing them in a broader integrated framework of long-term trends, better insight is obtained in the direction of individual trends.

Each layer in the framework refers to a different level of inertia, ranging from long-term trends with a duration of several decades to even longer trends that evolve over centuries. The method is tailored to address issues with a high level of uncertainty as defined as Level 3 uncertainty by Walker *et al.* (2010), which also recognises Level 4 or deep uncertainty. It is positioned in-between the forecasting and probabilistic forecasting methods that are well suited to deal with Level 1 and Level 2 uncertainty (Armstrong, 2001; West and Harrison, 1999) and the methods directed at addressing deep uncertainty, such as scenarios and adaptive pathways (Volkery and Ribeiro, 2009; Haasnoot *et al.*, 2013).

Level 3 uncertainty, in particular, links to methods for anticipating technological and social change that may either involve empirical observations, theoretical explanations, or ways to envision desirable futures and move towards them. Cyclical theory and empirical data on long economic cycles (i.e. so-called Kondratieff waves) offer an increasingly recognised potential to create a comprehensive empirical view on transformations that we are experiencing today (Wilenius, 2015; Wilenius and Kurki, 2017). They provide clear insights into the primary drivers of unfolding transitions, but in the absence of a theoretical explanation, they offer little insight into the underlying processes of change. De Haan and Rotmans (2018) discuss the state of play regarding our understanding of the way these transitions unfold and propose a theoretical framework for assessing the role of different types of actors in transitions. Another method for addressing Level 3 uncertainty is the three-horizons method that uses a group process to assess three distinct time horizons (i.e. first – present system; second – transition zone; third – future system) with the objective of identifying and creating narratives on possible pathways for organisational transformation towards a desired future (Sharpe *et al.*, 2016; ITC, 2020). Although these methods can be used to address plausible developments, which can be linked to Level 3 uncertainty (Van Dorsser *et al.*, 2018b), they are less specifically directed at reducing epistemic uncertainty by gaining understanding of the context of individual trends and their mutual interaction, which is the purpose of our method.

The method proposed in this paper uses desk research to analyse three layers of trends. The first layer concerns relevant megatrends with a duration of a few decades; the second layer concerns the long wave in economic life that has a duration of about 50 years and is closely linked to transitional processes taking place today; and the third layer concerns the gradual movement of trends that have already existed for over a 100 years. This system of trends is expected to provide sharper insight into the overall development of the world system, allowing trends to be placed in a broader perspective to reduce epistemic uncertainty and improve foresight. Based on a detailed description of the trends and key uncertainties and their mutual interaction in the integrated framework, narratives can be developed to prepare for future change. The use of narratives is similar to the approach in the three horizons method, but the proposed framework aims to provide a sharper view by considering the mutual interaction and inertia of trends.

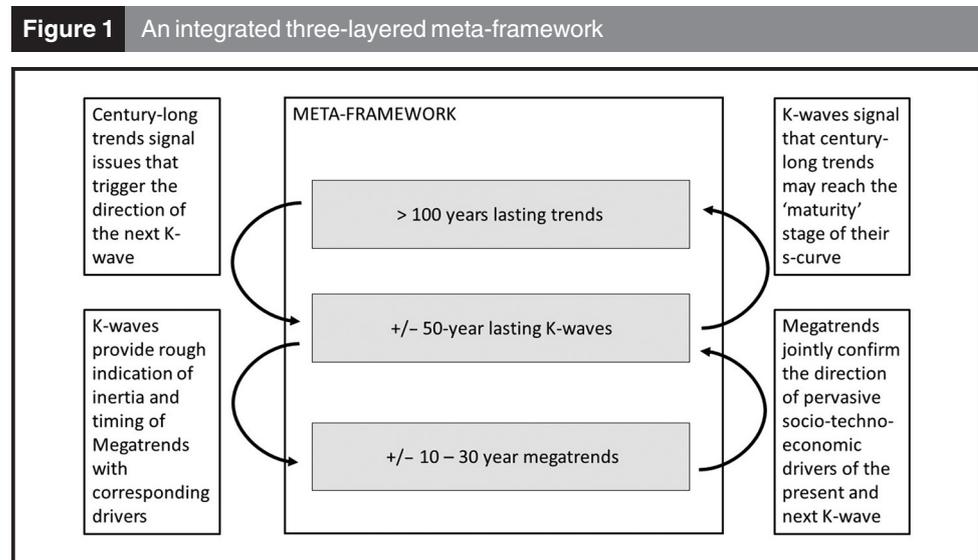
The framework was developed while carrying out a case study for the Port of Rotterdam (PoR) in The Netherlands (Van Dorsser *et al.*, 2018a). Reference to the case study is only made occasionally in the first part of the paper because the objective is to present a new theoretical framework and method as an integrated foresight approach. The discussion on the practical use of the method for assessing real-world policy issues as illustrated by the case study follows at the end of the paper.

The paper proceeds as follows. Section 2 presents the framework and describes the four steps of the integrated foresight method. Sections 3-6 discuss the application of the steps in practice, whereas Sections 7-9 illustrate the method by presenting a case study for the Port of Rotterdam. Section 10 summarises the main conclusions and elaborates on the further development and potential use of the proposed method in practice.

## 2. The proposed foresight method

The foresight method proposed in this paper is based on an integrated three-layered framework for improving foresight by systematically analysing aggregated long-term trends (or megatrends) with a different level of inertia in an integrated way at the overarching meta-level. Oxford Living Dictionaries (2018) refers to meta-level as “A level or degree (of understanding, existence, etc.) which is higher and often more abstract than those levels at which a subject, etc., is normally understood or treated”. The meta-level approach leads to insights in the broader context of individual trends.

The theoretical framework is presented in Figure 1. Each layer relates to trends with a different level of inertia. The top layer consists of trends with duration over 100 years. These highly aggregated trends usually follow a long-term transition path and are relatively certain. They can be assumed to continue for a few more decades, justifying mindful extrapolation. The second layer consists of the so-called Kondratieff waves or K-waves. K-waves refer to an about 50-years lasting cyclical movement in the world economy that is observed since the start of industrialisation a few hundred years ago. Empirical evidence reveals a firm link between the main drivers of the K-waves and the pervasive economic, technological and social developments taking place. Though the precise timing of K-waves is hard to predict, the cyclical pattern of the K-wave movement is clear, as are its main drivers. This layer offers relatively clear insight into the dynamics of our world and the direction of technology and socio-economic trends. The third and the least aggregated layer consist of a plurality of



megatrends with a considerable impact and an expected duration of a few decades. These megatrends often relate to emerging technologies, such as 3D-printing and autonomous driving. They are well recognised and widely discussed in various media.

Analysing trends with different inertia creates awareness of the degree of uncertainty at each layer. The real added value of the proposed approach, however, lies in the interaction between distinct layers. Each layer adds insight into the movement of the adjacent layer(s). The century-long trends signal the issues that trigger the main focus and direction of the next K-wave. The movement (or regularity) of K-waves provides a rough indication for the timing and relevance of newly developing megatrends and their driving forces. The identified megatrends confirm the direction of the pervasive socio-techno-economic drivers of the K-waves. And finally, the K-waves indicate that some century-long trends may reach the maturity stage of their S-curve and act as a slow steering force on the century-long trends. By placing trends in a broader perspective, insights obtained in the individual layers improve understanding of the direction of trends in the adjacent layers and adds insight into the evolution of individual trends. This approach could, in theory, provide additional insight into the inertia and direction of long-term trends, aiming at sharper foresight for better decision-making. Professional foresight practitioners may have already developed similar insights over time by studying trends and applying existing foresight methods, but decision-makers often lack this experience. Therefore, we propose an integrated foresight method based on the three-layered framework in [Figure 1](#), which consists of the following steps.

- *Step 1:* Identify megatrends and key uncertainties with a duration and potential impact of at least one or two decades and categorise these trends by theme.
- *Step 2:* Filter out trends with a duration of at least one century because these can be expected to remain relatively stable over the next few decades.
- *Step 3:* Analyse the dynamic behaviour of about 50-year lasting economic cycle (i.e. the K-wave) and its primary drivers.
- *Step 4:* Assess the linkage between the layers and integrate all three layers into a broader meta-framework such that the context of the individual trends stands out.

The existence of a clear framework for analysing trends enhances the options for decision-making under Level 3 uncertainty, as the traditional approach for dealing with increased future uncertainty is to shift from forecasting (i.e. method for dealing with Levels 1 and 2 uncertainty) to assessing a range of scenarios (i.e. Level 4 when considering possible scenarios). Scenarios are well suited to anticipate possible changes, but commercial plans that are designed to accommodate a broad set of requirements presented by innumerable scenarios require high investments and risk becoming non-competitive. In a commercial environment, the challenge is not just to envision developments with a possible effect on the business, but more importantly, to assess which of them are plausible, given a thorough understanding of the underlying system. To stay competitive in a commercial environment, one does not have the luxury to invest in plans that are robust under numerous possible developments. Instead, one has to focus on the more plausible developments, which can be identified on the basis of a comprehensive understanding of the system, as obtained from the proposed framework.

To develop strategic insight and use this to prepare the business (or another relevant policy domain) for upcoming threats and to seize future opportunities, the following additional steps can be taken.

- *Step 5:* Conduct a thorough strengths, weaknesses opportunities, and threats (SWOT) analysis starting with the identification of threats and opportunities using insight from the three-layered framework, followed by an assessment of the strengths and weaknesses related to these threats and opportunities.

- *Step 6:* Create a limited set of “trend-based narratives” over the future development of the policy domain (e.g. the business) considering the recognised relevant external threats and opportunities (e.g. described by plausible storyline scenarios) in combination with the strengths and weaknesses of the organisation.
- *Step 7:* Elaborate on the trend-based narratives to create a broader vision and strategy for the development of the business, or another relevant policy domain.

A *narrative* is a story written or told, usually in great detail. Well-defined trend-based narratives are useful for creating a collective or shared view over the future and identifying threats and business opportunities, which is a stepping stone towards realising a vision and strategy.

The following four sections provide a general discussion of the four steps in the three-layered foresight method, in which the description of the trends and key uncertainties is based on our interpretation of available sources and intended to illustrate the kind of insights that could be obtained from applying the framework. The subsequent sections discuss the practical application of the method in support of decision-making for an actual case study for the Port of Rotterdam.

### 3. Step 1: identifying relevant megatrends

Step 1 involves the systematic screening of megatrends and key uncertainties relevant to the subject under consideration, neglecting the inertia of these trends. Megatrends are named after [Naisbitt \(1982\)](#). They can be distinguished from normal trends by their time horizon, reach and intensity of impact. Megatrends can be observed over the decades; impact comprehensively on all regions; and impact powerfully and extensively on all actors ([Z-Punkt GmbH, 2020](#)). Key uncertainties are defined as uncertainties that are considered plausible and likely to have a major impact on the system under consideration in case they appear (such as e.g. the development of nuclear fission power or the event of war). Because numerous trends and key uncertainties exist, a well-structured approach is required to filter out relevant ones.

Step 1 starts with identifying overarching themes related to the issue at hand for which the well-known STEEP classification is suggested, as commonly applied in the UK ([Habegger, 2010](#)). STEEP stands for Societal, Technological, Economical, Environmental and Policy. Following a suggestion of [Watson \(2013\)](#), extra letters may be added to tailor the method, such as an extra E for Energy, and extra E for Employment, an extra P for Population and an extra I for Identity, turning STEEP into STEEEPPPI. Whether such additions are useful is case-specific. For example, an extra E was added for Energy in the mentioned case study for the Port of Rotterdam as the port is a major player in handling energy products.

The following action is to identify relevant megatrends and key uncertainties based on discussions with experts, literature research, internet searches and news articles, which are also standard tools for horizon scanning and emerging issues research ([Slaughter, 2009](#); [Miles and Saritas, 2012](#)). A complicating factor at this stage is that it is impossible to be sure that all relevant trends and uncertainties have been included. The risk of omitting important trends should be recognised and, if possible, mitigated by, for instance, involving experts with a different background. The next step requires examining the potential impact of the trends and key uncertainties on the issue at hand, which can also be based on literature research and expert opinions.

The general outline of the method in this paper does not allow for an in-depth discussion of relevant megatrends, though some trends are mentioned in [Table 1](#). Elaborate descriptions of identified megatrends and key uncertainties are provided in the mentioned case study.

**Table I** Impact of developments (mega-trends and uncertainties) in STEEEP categories

STEEEP category	Mega-trends and uncertain developments
Societal	Stagnating population growth and possible decline of population in western Europe result in lower consumption and transport volumes Urbanisation reduces material and energy consumption per capita Stagnation/decline in middle-class income levels reduces consumption and enhances counter-globalisation forces, both reducing international transport
Technological	Ongoing automation and artificial intelligence change logistical and transport systems (e.g. automated terminals, 3D printing, autonomous driving) Decline in throughput of fossil products; increase of renewable energy carriers; changing industrial and logistical activities
Environmental	Decline in transport of raw materials; increase in transport of recycled and renewable (often bio-based) materials Ecosystem degradation, decline of already insufficient natural resources in Europe and a new focus on a circular economy boosts recycling and upcycling activities Climate change affects accessibility and competitiveness of ports (sea level rise), downtime (extreme weather) and IWT hinterland connections Growing pressure on ecosystems, because of pollution and effects of climate change, could result in increased food exports overseas
Economic	Loss of jobs because of ongoing automation, robotics and artificial intelligence Offshoring of jobs to low-wage countries; this trend is now reversing but on balance there is still a shift of labour to low-wage countries
Energy	Counter-globalisation forces and creation of new trade barriers Strong growth of energy demand in developing and newly industrialised countries requires new energy sources Long-term decline in energy returns on energy invested (EROI) stimulates a shift from fossil to renewables as the latter become more cost-effective Uncertain role of LNG as a transition fuel and uncertain rate of development of technologies related to renewables and synthetic fuel production
(Geo)Political	Geopolitical tensions increase risk of cyber-attacks and other terrorist or warfare attacks on the port Military encounter between NATO and Russia can be expected to result in economic sanctions affecting shipments of Russian oil to Europe and transshipment containers from Europe to Russian ports in Baltic sea US conflict with China could severely reduce (or bring to a hold) container volumes between China and Europe

**Note:** IWT = Inland waterway transport

#### 4. Step 2: century-long trends

Once the overall set of trends and key uncertainties is obtained, Step 2 analyses the trends identified in Step 1 and filters out the trends that have existed for a century or more, making use of corroborating time series. These trends belong to the top layer of the framework. They have low inertia, are relatively stable and likely to head in the same direction for at least few more decades. Acknowledging that the list is not comprehensive, the following century-long trends were identified and assessed in greater detail in the mentioned case study report ([Van Dorsser et al., 2018a](#)):

- secularisation and individualisation;
- population growth;
- urbanisation;
- the nature of activities and social power;
- energy and raw material use;
- connectivity and increased data exchange;
- technological progress and economic output;
- climate change and environmental degradation;
- (reducing) transport costs and globalisation; and
- shifts in geopolitical world order.

For each of these trends, we assessed the potential impact on the global trade and transport volumes as well as on the activities undertaken in the port (i.e. the core subject of the case for which the method was developed). These trends are also likely to be relevant to other foresight studies. This section discusses the ten century-long trends, based on our understanding and subjective interpretation of the trends. It provides an illustrative application of the method for future foresight studies. The discussion includes some detailed aspects specific to our case study to illustrate how the century-long trends can be tuned to provide insight into the subject under consideration.

*Secularisation and individualisation* have an impact on population growth, migration, geopolitical stability, populism, nationalism and anti-globalisation. In Christian-rooted countries, it took almost 500 years (starting with Luther's 95-thesis and the 80 years' war in the Netherlands) to reach the secular state that these countries have today. In contrast to this slow gradual bottom-up process, Islamic countries such as Iran and Turkey became a secular state almost overnight in an enforced top-down process under influence of the British Empire and Western ideology in the 1920s. Though some people in these countries want to modernise, others still have difficulty with the swiftly enforced change, which backlashed resulting in the ongoing tensions and conflicts in the Middle-East, Africa and South Asia today that also affect the Western world through extremism and terrorism. In analogy with the long secularisation process in Europe, it can be expected that these tensions remain a source of conflict for many generations. The resulting conflicts and acts of terror are, in combination with induced refugee flows, higher birth rates of religious (often Islamic) minorities in Western countries, and declining welfare growth for the bottom 99 per cent of the population, a growing source of populism, nationalism and anti-globalism in the West.

*Population growth* has a severe impact on the world. Population growth, of which the rate is affected by religiosity, puts a constrain on resource availability, and also affects geopolitical power, poverty and migration. Based on [UN DESA \(2017\)](#) projections, the population is expected to remain growing throughout the twenty-first century in Africa, where it is booming, as well as in the USA through a stable continued growth. Growth is also strong in India where it is expected to peak around 2080. The European population is stabilising and expected to show moderate decline from about 2040 onward. In China, the population is near its expected peak in 2030 and thereafter expected to face substantial decline throughout the century. Russia is already facing a severe continued population decline. Changes in population growth affect the geopolitical power balance, in which India is gaining regional importance over China and Russia, and in which China and Russia are less likely to fully take over the hegemony of the USA. Africa's growth will, together with climate change induced poverty and starvation, enhance migration towards wealthier regions, fostering populism and the anti-globalisation movement in western countries. For our case study, this likely results in reduced international trade and transport volumes. In addition, aging populations also require fewer material goods and more services, which also reduces transport volumes handled by major seaports.

*Urbanisation* is a direct result of the growing population in most parts of the world, but it is also induced by other trends such as the shift in the nature of activities and social power, and by ongoing connectivity and technological progress through specialisation. With respect to our case study, urbanisation changes living patterns and affects consumption in a way that it reduces demand for material goods (i.e. smaller houses, less cars, less energy demand) and increases the demand for services.

*The nature of activities and social power* is gradually shifting from agriculture and land ownership in the pre-industrial time (up to about the eighteenth century) to industrial manufacturing, capital and possession of resources (since the Industrial Revolution), to services based on information and knowledge in the post-industrial age from about the year

2000 onwards (Van Wyk, 1984; Spies, 1998). This trend fosters connectivity, urbanisation and individualisation.

*Energy and raw material use* show a long path along a centuries-long transition curve in which raw material and fossil energy resources are extensively exploited resulting in vastly lower energy returns on energy invested (EROI), down from over 100 in 1930 to below 8 for new discoveries in 1970 and only about 5 for shale oil and 2-4 for tar sands (Murphy and Hall, 2010). Similar trends of declining ore grades are also reported for mining products, which implies that more efforts (costs and energy) are required to mine a tonne of material. Until recently, advancements in mining techniques have been able to offset the increasing costs of fossil fuel and mineral depletion, but this trend seems to have reversed around the year 2000 (also for agricultural products). Further cost reductions on energy are only possible through advancing renewable energy, which is becoming competitive and starting to gain noticeable market share. Cost reductions on material use depend on developing advanced recycling, which is a growing industry.

*Connectivity and increased data exchange* are an ongoing trend that seems embedded in human nature traced back to ancient times with development of trade routes (both maritime and over land) and the invention of writing. It accelerated with the invention of the printing press in the fifteenth century that triggered the renaissance. Connectivity boosted during the industrial age by the invention of new transport means (e.g. canals, railways, paved roads, air transport), new means of communication (e.g. telegraph, telephone, fax, mobile, social media), computers and new data carriers (e.g. pons card, gramophone, magnetic disk, SSD). After the introduction of the internet, computers were swiftly connected to the World Wide Web that is now offering a broad range of services including online booking and online shopping. The following step is to connect all kinds of smart machines to the Internet of Things (IoT), including e.g. air conditioners, fridges, cars, etc. and to make extensive use of sensor technology and big data to improve business operations. Next steps that are being researched today are the development of bionics and the connect of the human brain to the cloud through augmented sensing, ultimately moving towards the creation of cyborgs.

*Technological progress* is closely related to the supply side of the economy, as technological progress is usually measured in aggregated terms of increasing factor productivity and increasing labour productivity. Labour productivity, and therefore also *economic output* (per worker), has increased dramatically over the past 200 years as a result of higher education levels, more capital intensive processes and advancing technology levels through an almost exponential growth in research output that cannot be sustained nor be expected to continue to offset the diminishing returns on technology development (Fernald and Jones, 2014). Though not universally agreed on, we conclude that labour productivity in technological forefront countries follows a transition s-curve, for which economic output is eventually bounded by the size of the working age population (Van Dorsser, 2015, 2018a). This view is in line with the conclusion of Gordon (2016) that the growth since the Industrial Revolution is a result of a number of life-altering innovations that cannot be repeated, for which he contends that US productivity growth has already slowed down to a crawl and is likely to further decline.

*Climate change and environmental degradation* are a direct effect of overexploitation and overconsumption of material goods and fossil energy resources. Climate change affects our global living environment in many harmful ways. Devastating are the negative impacts on food yields, dying of marine ecosystems, extreme weather conditions, floods and the impacts of sea level rise. In combination with environmental degradation, it deteriorates the ecosystems by acting as a driver of food-induced conflicts, starvation and climate-induced migration, especially in combination with rising poverty levels. On the positive side, climate change and environmental degradation stimulate global awareness for sustainability that shifts focus on, e.g. reduction of carbon footprint, renewables and recycling. Specific to our

case study, climate change results in melting of polar ice and the creation of new sea routes via the arctic that are considerably shorter than existing ones. Moreover, global warming also reduces the frequency of river ice events for inland shipping; increases the downtime of port terminals because of extreme weather events; and causes many other subject-specific impacts.

*Transport costs* have been declining over a long period fostering *globalisation*. [Oosterhaven and Rietveld \(2003\)](#) found that real costs for maritime transport declined by a factor 7.5 from the late eighteenth century to the second half of the twentieth century and have remained relatively stable thereafter, though indicating a slight possible increase. In a similar way, they showed that inland transport costs declined by a factor 5.5 for road transport, and by about a factor 4 for rail transport, over the course of the twentieth century. International sea transport costs are now so low that further reduction is fairly difficult, indicating that an increase is not unlikely. This could also be anticipated from the all-time low in the costs of fossil energy and raw materials around the year 2000 (with renewable fuels for sea transport still requiring a few decades to become cost-effective). This implies that a lower cost of international transport is no longer a key driver for ongoing globalisation.

*Shifts in geopolitical world order* are subject to low inertia changes, in which China and India were once the leading powers prior to the Industrial Revolution. Following the Dutch Golden age and the Industrial Revolution, the “Western” world gained a dominant position first through the British rulership and later through the supremacy of the USA. However, from the 1960s onward, China built up substantial economic and military power and teamed up cleverly with Russia and other countries to undermine the affectivity of Western-originating institutes such as the UN Safety Council, while creating their own institutes, including the Shanghai Cooperation Organisation (SCO). The shift of power from “West” to “East” can potentially result in an all devastating war, but a shift of power without war could be more likely as:

- [Levy and Thompson \(2011\)](#) showed that the percentage of years in which great powers fought each other has fallen dramatically over the past five centuries; and
- because when analysing advancements in the economic power, one can observe the shift of economic power from the USA to China to lose momentum and start stabilising.

This creates a bipolar world order, with two power blocks being NATO and SCO. The USA still has a steady continued growth of its population, economy and technology base, whereas Russia seems already over the top of its economic power, and China is confronted with an expected decline of population and a long-term slowdown of economic growth (with growth gradually moving towards the lower growth path of developed technological frontier countries). Moreover, India, which is more Western-oriented, has joined the SCO and is gaining economic relevance in the region, acting as a stabilising factor. So, presumably, the world will, for a sustained period, remain caught in a bipolar power balance in which the democratic norms and values of the “West” are sacrificed for a more pragmatic “mind your own business and don’t interfere with our own “domestic” affairs” approach. This also implies that the conflict-solving ability of our world is partly disabled, resulting in more severe impacts of geopolitical conflicts, such as obviously being observed in Syria today. However, in spite of this trend of moving away from global military escalation, future geopolitics remain rather uncertain (especially compared to other trends) and are suggested to remain included as key uncertainty.

There are a few remarks. First, economic growth is subject to both the supply and demand side. Trends with respect to technology development and labour productivity growth relate to the supply side of the economy, but another important trend is evolving at the demand side that relates to increasing wealth and income inequality since the 1970s (now lasting about 50 years). This trend is already and could further reduce economic output in the future ([Brueckner and Lederman, 2015](#)). Second, the rise of China as a dominant world

power is strictly not a century-long trend, but shifts in global leadership, since the middle ages, seem to appear almost every 100 years ([Modelski and Thompson, 1996](#)).

### 5. Step 3: Kondratieff waves

Step 3 analyses K-waves which are a linking pin between the individual megatrends and the centuries-long lasting trends. They concern a cyclical movement around the centuries-long trend in technology development and per capita economic growth. Cyclical movements have been studied ever since the Industrial Revolution started to cause social crises and many cycles of varying lengths have been identified ([De Groot and Franses, 2009](#)). The more commonly reported cycles are:

- 3-5-year inventory cycle of Joseph Kitchin;
- 7-11-year business cycle of Clement Juglar;
- 15-25-year infrastructure swing of Simon Kusnets; and
- 45-60-year long wave of Nikolay Kondratieff.

For the proposed framework, the 45-60-year [Kondratieff \(1926\)](#) wave is the most relevant. Kondratieff waves are related to the pervasive drivers of our global society and the world economy ([Grübler and Nakićenović, 1991](#); [Ayres, 1990a, 1990b](#)). Their close relationship with the diffusion of new technologies and the development of new infrastructure networks make the K-wave useful for identifying future trends and their inertia (or momentum) ([Grübler, 1990](#)). The other cycles are less relevant, though [Juglar's \(1862\)](#) 7-11-year business cycle provides valuable insight into the movement of the K-waves ([Van Duijn, 1983](#)). [Schumpeter \(1939\)](#) already observed strong regularities in the movement of the K-waves and suggested each K-wave to consist of six Juglars. [Van Duijn \(1977\)](#) refined this view and proposed that K-waves need not consist of six Juglars, but can also be composed of five Juglars, at least in cases where no war is following the prosperity period as is frequently the case.

The cyclical pattern of the K-waves can be represented in various ways. The most basic is the one with an upswing period followed by a downswing period. [Schumpeter \(1939\)](#) proposed a sinusoidal four-phase model consisting of four phases: prosperity, recession, depression and recovery. A revised phasing was proposed by Kuznets because the original phasing did not comply with the upward and downward movement of the waves. His revised scheme, also adopted by [Van Duijn \(1977\)](#), differs in that the starting point of the upswing phase is located at the beginning of the prosperity phase, and the starting point of the downswing phase is located at the end of the recession phase.

#### 5.1 Chronologies of the K-waves

There is no consensus on the exact timing of the subsequent K-waves because:

- different economic parameters are examined to identify the waves;
- the cyclical movement has not been synchronous in all countries; and
- different interpretations and weights are given to the observed data.

[Table II](#) shows the chronology of the historical K-waves according to [Van Duijn \(1983, 2007\)](#) and extended by the authors. According to this chronology, K-waves are composed of five Juglars, of which two are prosperous periods. Occasionally, the length of K-waves was extended by a period of war following the prosperous periods, with high geopolitical tension in the effort of securing a country's needs. WWII was a large exception taking place in the recovery phase of the third K-wave. The out-of-sequence timing of WWII can be explained by the Versailles Treaty that was imposed on Germany after WWI that placed impossible

**Table II** Chronology of K-waves

<i>K-waves</i>	<i>First</i>	<i>Second</i>	<i>Third</i>	<i>Fourth</i>	<i>Fifth</i>
Trough	1782	1845	1892	1948	1992
Prosperous	1782-1792	1845-1856	1892-1903	1948-1957	1992-2000
Prosperous (war)	1792-1802 (1802-1815)	1856-1866	1903-1913 (1913-1920)	1957-1966	2000-2009
Recession	1815-1825	1866-1872	1920-1929	1966-1973	2009-2018E
Peak	1825	1872	1929	1973	2018E
Depression	1825-1836	1872-1883	1929-1937	1973-1980	2018E-2027E
Recovery	1836-1845	1883-1892	1937-1948	1980-1992	2027E-2036E
Total cycle time	63 years	47 years	56 years	44 years	44 years
Idem excluding war	50 years	47 years	49 years	44 years	44 years
Upswing period	43 years	27 years	37 years	25 years	26 years
Idem excluding war	30 years	27 years	30 years	25 years	26 years
Downswing period	20 years	20 years	19 years	19 years	18 years

Source: Van Duijn (1983, 2007), extended by author from 2007 onwards

restitution demands on the nascent Weimar Republic and gave birth to national-socialism movement in Germany.

There is no universal agreement on the chronology of the K-waves. According to some, the downswing period of the fifth K-wave started around 2008-2010 (say 2009\*) after the housing bubble and credit crisis (Korotayev and Tsirel, 2010; Allians Global Investors, 2010). However, based on the extended chronology of Van Duijn, the K-wave would have been expected to peak around 2018E (though this has not occurred yet) or at least in the period from 2016E to 2020E (starting with 2009\* and considering a 7- to 11-year Juglar). Based on Van Duijn's historical pattern, the next upswing period of the sixth K-wave can be expected around 2036E (or slightly later assuming a 9-year period from the delayed peak of 2018E), though others expect the upswing period one business cycle earlier, i.e. around 2027E. Based on these rough estimates, we conclude that new business models are likely to develop over the next one or two decades and become leading in the period around 2030-2040. This is when the nature of doing business is truly likely to change.

### 5.2 K-waves and the diffusion of technology

There is abundant empirical evidence that social-, technological- and economic change affect the cyclical behaviour of K-waves. Periods of growth and expansion of economic activities are punctuated with phases of fundamental change in the structure of the economy, the technology base and many social institutions and relations. After a certain stage, the dominating socio-techno-economic paradigm that has led to the previous upswing phase reaches its limits of social acceptability, and the environmental compatibility begins to saturate (Grübler and Nakćenović, 1991). Historical evidence suggests that in many cases, the economic impact of an important innovation contributed little to the "next" upswing but may have contributed significantly to subsequent ones (Ayres, 1990a, 1990b). This implies that the emerging technologies of the  $n^{\text{th}}$  wave will generally not become dominant until the  $n + 1$ th wave, which makes it possible to identify dominant technologies of the next K-wave through examining the emerging technologies of the present wave.

### 5.3 Anticipating drivers of the next K-waves

The 5th K-wave was mainly driven by growing global mobility and ongoing exploitation of fossil fuel resources, electrification and ICT technologies, which enabled far-reaching integration of people, systems and trade, but at cost of the environment. The principal drivers of this pervasive development can be recognised as "globalisation and ICT".

The beginning of the sixth K-wave coincides with the end of the “Industrial Age” (referring to what was once called “heavy industry”) and the start of the “Information Age”. Over the past few decades, the world has been confronted with a number of imminent crises including environmental and climate change crisis; raw material and energy crisis; potential food crisis; financial, deficit and debt crisis; and raising social discontent caused by growing income and wealth inequality and loss of jobs. In response, there is an increasing desire for a more sustainable society and the next K-wave can, therefore, to some extent, be expected to be driven by these responses. The ongoing trend of making machines smarter and connecting them to the internet (i.e. the IoT) amplifies the trend towards connectivity, for which the drivers are aligned with the sustainability driver through enabling efficiency gains and smart solutions. The principal driver of the sixth K-wave is thus linked to “sustainability” and a shift from hyper globalisation to a reduced level of globalisation in combination with ongoing connectivity now reflected by a shift from “ICT” to “IoT”. These drivers are visible in many of today’s megatrends.

The notion that “sustainability” and “digital connectivity” are considered principal drivers of the sixth K-wave is broadly accepted (Hargroves and Smith, 2005; Moody and Nogrady, 2010; Adams and Mouatt, 2010; and Allians Global Investors, 2010). The critical problems of modern society provide an indication of the direction of future megatrends. In line with these trends, the primary drivers of the sixth K-wave are, amongst other, expected to relate to burning fewer fossil fuels; enhancing transparency and corporate social responsibility; and increasing energy and material efficiency, recycling and data-mining. However, increased network connectivity will also enhance threats of fake news, cybercrime and cyberterrorism.

## 6. Step 4: interaction between the layers

Step 4 analyses the interaction between the layers in [Figure 1](#) and the insights that the layers offer each other through a better understanding of the broader context at the meta-level.

### 6.1 Insight from century-long trends into drivers of next K-wave

Century-long trends signal issues that are likely to trigger the direction of the next K-wave and help identify pervasive drivers more clearly. Ten century-long trends were identified in Section 3. The forces exerted by these trends drive counter-globalisation, enhance sustainability and increase connectivity. They contribute to the pervasive shift from globalisation towards sustainability and the continuing trend towards hyperconnectivity, reflected in the shift from ICT towards IoT. These are, in fact, the primary drivers of the sixth K-wave. A discussion follows.

- *Secularisation and individualisation trend* explains the tensions within the Islamic world resulting in nationalistic and populist forces in the “West” strengthening the reverse globalisation movement through protectionism and signals the end of a hyperglobalisation era (symptoms: Brexit, Trump, etc.).
- *Nature of activities and social power trends* indicate a shift from energy to information as a source of power. The implications are twofold. First, the shift implies that the future world may be less energy-constrained because of the availability of renewable energy. Second, the shift towards information as a prime source of power matches the shift towards hyperconnectivity.
- *Growing population trend* amplifies the trends in energy- and raw material use as a larger population require more resources and spur demand for renewables and recycling. This trend is, therefore, a major driver for sustainability.

- *Urbanisation trend* increases connectivity and social awareness on pollution and unsustainable exploitation of the earth's resources, thus driving sustainability. The urban population lives in more compact houses and is less likely to own a car, enabling reduced energy and raw material consumption (towards sharing goods instead of owning them). This is also a driver for sustainability. Moreover, (educated) urban population is likely to accelerate the shift from ICT to IoT.
- *Energy and raw material use trend* highlights renewable energy use as well as more sustainable material use through refuse, reduce, reuse, recycle, etc. The growing world population and the economic growth in developing and newly industrialised countries (NICS) leading to an increased demand drive this trend, as do climate change-related policies calling for renewable energy development. The supply of renewable energy requires smart grids, which also drives the shift from ICT to IoT.
- *Technological progress and corresponding economic growth trend* foster reverse globalisation, sustainability and development of IoT in several ways. At the disaggregated level, new technologies are developed in fields of sustainability, big data and IoT. At the aggregated level, technological progress (automation, robotics and artificial intelligence), displaces workers. Unemployment and inequality foster populism, nationalism and reverse of (hyper)globalisation.
- *Connectivity and increased data exchange trend* align with the trend towards hyperconnectivity, i.e. connecting devices to the IoT. Availability of sensor data, e.g. over-pollution levels help to create transparency and drive sustainability initiatives. The next step is to connect the human body to the "internet", through a fusion of technologies in the physical, digital and biological worlds.
- *Climate change and environmental degradation trends* are both strong drivers of sustainability and act in two ways. First top-down via environmental and climate policies, and second bottom-up whereby consumer awareness and corporate social responsibility contribute to increased environmental compliance (sustainability and reducing footprint is becoming a core objective for major brands). Climate change and pollution reduce agriculture yield and fish catch, causing starvation and (mass) migration, and thereby increasing anti-globalism in Western countries.
- *Reducing transport costs and globalisation trend (being reversed)* is now showing signs of saturation and reversal as sea transport costs have reached a point of no further decline around the year 2000. Declining transport costs therefore no longer serve as one of the main drivers for globalisation.
- *Shifts in political world order trend*, or more specifically the shift from US hegemony to a multi-polar (or bipolar) world in which NATO and SCO both vie for power, make the world a less stable and less predictable place. This instability and malfunctioning of Western institutes (such as the UN safety council) increase geopolitical tensions and act towards reversed globalisation.

To conclude, each of these ten century-long trends drive reverse globalisation, sustainability and hyperconnectivity. The century-long trends, therefore, establish that (hyper)globalisation is on its reverse, which underlines the shift in primary drivers of the K-wave and is confirmed by recent data on global trade over gross domestic product (IMF, 2019; UNCTAD, 2019).

## 6.2 Insight from K-waves on the movement of century-long trends

The primary drivers of the K-wave, too, influence the direction of long-term trends, but changing (or bending) the curve of a century-long trend takes time. The influence of the K-wave drivers on century-long trends is presumably not as large as the other way around.

However, the shift from globalisation to sustainability creates forces tending to align the century-long trends, making them co-dependent so that the entire system moves in one direction. The impact of the K-wave drivers on the century-long trends is as follows:

- *Secularisation and individualisation*: Ongoing digitalisation and interconnected world act as an amplifier for secular tensions (i.e. positive feedback loop).
- *Nature of activities and social power*: Sustainability trend stimulates the production of (affordable or even cheap) renewable energy reducing the need for fossil reserves. This undermines the role of fossil energy resources as an economic power source. Research and development of knowledge are required in the field of renewables and supports the shift from energy to information and knowledge as a prime source of power (i.e. positive feedback loop).
- *Population growth*: Sustainability stimulates sustainable population growth (in line with bearing capacity of the earth's environment) through more sustainable food yields and a healthier living environment (i.e. positive feedback loop).
- *Urbanisation*: Carbon tax, digitalisation and increasing connectivity are drivers of further urbanisation (i.e. positive feedback loop).
- *Energy and raw material use*: Sustainability is a major driver for the shift from fossil to renewable energy. Technological advancement in renewable energy is undermining the business case for new fossil investments as the time left to recover capital expenditures is becoming smaller. Cost of energy may increase in the medium term but is expected to decline and stabilise with advancing renewable energy and fuel technology. Recycling is gaining importance as a resource for manufacturing materials (i.e. negative feedback loop on fossil energy and raw material exploitation, positive feedback on renewable energy and sustainable material use).
- *Technological progress and economic growth*: At a disaggregated level, sustainability stimulates many technological developments, including 3D-printing and local bio-based production. Sustainability is expected to spur economic output (for a few decades) as the energy and raw material transition creates new markets and new employment. In the longer term, more sustainable tax regimes may hopefully improve economic output by reducing inequality, but this is uncertain (i.e. positive feedback loop on technological progress and economic growth).
- *Connectivity and information exchange*: This trend aligns with the increased digital connectivity driver of the K-wave, now reflected in the shift from ICT to IoT (i.e. positive feedback loop on connectivity).
- *Climate change and environmental degradation*: Though the inertia of the climate change trend is much larger than the inertia of the pervasive drivers of the K-waves, the sustainability driver of the sixth K-wave helps slow down climate change, pollution and environmental degradation (i.e. a negative feedback loop).
- *Reducing transport costs and globalisation (being reversed)*: Sustainability affects transport cost and globalisation in various ways. In the short term, it adds to transport cost by demanding sustainable operations. In the long run, sustainability will make transport more efficient and cost-effective. Also, renewable energy will eventually secure lower fuel costs compared to future fossil fuels (i.e. negative short-term and positive long-term feedback loop on reduced transport cost and globalisation).
- *Shifts in political world order*: The drive towards sustainability will reduce the need for raw materials and fossil fuels, thereby reducing global tensions (i.e. negative feedback loop on increasing global tensions).

It can be concluded that the main drivers of the next K-wave (i.e. sustainability and increased digital connectivity) impact all century-long trends.

### 6.3 K-waves and indicative timing of megatrends

Section 5 mentioned that major innovations usually take place during the downswing period of the Kondratieff wave, but that it takes up to the next upswing period (expected around 2030/2040) before they materialise as primary drivers of a new socio-techno-economic paradigm. This implies that megatrends, such as autonomous driving and 3D printing will likely evolve from being a novelty to a standard commodity over the next one or two decades and become dominant in the period thereafter.

### 6.4 K-waves and confirmation from megatrends

The direction of the identified drivers of the next K-wave is confirmed by analysing current megatrends and their enablers, such as emerging technologies. These show alignment with the primary drivers of the present K-wave. For instance, many emerging technologies of the present fifth K-wave are related to sustainability and increased network connectivity (as reflected by the shift towards IoT). Such trends can be recognised as dominant drivers of the next sixth K-wave. [Table III](#) lists some megatrends that were identified in the mentioned case study and confirms sustainability and increased network connectivity as sixth K-wave drivers.

Summing up, the application of the proposed foresight method, as discussed in Sections 3-6, enables a systematic assessment of trends and key uncertainties, in which our understanding of individual trends and their mutual interaction is improved by placing them in the broader perspective of an integrated framework of trends. The recognition of three distinct layers that communicate via the K-wave layer provides valuable insight into the inertia and rough timing of many of today's megatrends such as 3D-printing and autonomous driving. The framework, therefore, has the potential to improve foresight and reduce epistemic uncertainty for decision-makers. A discussion on potential practical implications follows in the next section.

**Table III** Megatrends confirming sixth K-wave drivers

Type	Trend
Social	Hyperconnectivity, towards a condition in which all people and systems are connected
Technological	Focus on renewable energy, smart grids, recycling and the use of renewable materials. Ongoing miniaturisation (nano-technology and DNA), bio-based and avoiding transport with 3D printing Shift towards digital services, digitalisation and further integration of systems. Shift from ICT to IoT Social media spreading information (but also disinformation), making global developments more transparent (and hopefully more sustainable)
Economic	Automation, robotics and artificial intelligence causing loss of jobs and decline of middle-income class in the Western world. Together with opposition against offshoring to low-wage countries and increasing income and wealth inequality, causing discontent amongst population and counter-globalisation forces through populism and nationalism
Environmental	Various trends with respect to pollution and climate change highlight the imminent need for more sustainability
Energy	Cost of renewable energy sources, such as wind and solar, becoming lower than the cost of fossil fuels at favourable locations. Substantial investments in new energy-generating capacity already based on renewables Decentralised energy production, electrification and use of batteries (e.g. storage of energy in batteries of vehicles) Advancement in technology for bio-fuel and synthetic fuel production
Political	Various trends indicating a period of increased tension because of change in global power balance, resulting in reduced power of Western institutions (such as United Nations), increased number and intensity of conflicts and a reverse globalisation movement

## 7. Step 5: SWOT analysis

Based on the integrated framework of trends and key uncertainties developed in the previous sections, we can proceed to apply the framework to develop strategic insight and use these insights to prepare the concerned entity for upcoming threats and opportunities. The first step in this process is to conduct a thorough SWOT analysis. This is illustrated by a case study for the Port of Rotterdam (PoR), which is the largest port in Europe and well connected to the West-European hinterland by means of road, rail and inland waterway transport. A summary of the identified threats and opportunities, as well as the strengths and weaknesses in relation to these threats and opportunities, is presented in [Table IV](#).

The identification of the threats and opportunities has taken place on the basis of the insights gained from the presented framework [and supporting material published in [Van Dorsser et al. \(2018a\)](#)]. Note that [Table I](#) already paid attention to the impact of societal megatrends on the transport system and the port environment.

## 8. Step 6: trend-based narratives

By analysing the strengths and weaknesses of the port in conjunction with the threats and opportunities that were identified on the basis of the three-layered framework, it becomes possible to develop a number of trend-based narratives for various clusters of port activities. For means of illustration, we will now address the narratives on the liquid bulk and chemical, the dry bulk, the container and the offshore construction and recycling sector in the PoR. For these sectors, several threats and opportunities are combined in the narrative, which is logical as multiple trends exert forces on the port environment simultaneously.

**Table IV** SWOT analysis for Port of Rotterdam

<i>Strengths</i>	<i>Weaknesses</i>
<p>Largest port in Europe, with deep access channel that can facilitate world's largest tankers and bulk carriers</p> <p>Excellent hinterland connection by means of road, rail and inland waterway transport</p> <p>Some void space for new activities available because of recent expansion of new port area (2nd Maasvlakte)</p> <p>Different-sized container terminals at various locations, with the largest ones closest to the sea</p> <p>Existence of major petrochemical industry cluster and upcoming bio-base cluster</p> <p>Existence of major shipyards and home base for world's largest crane vessels.</p> <p>Existence of strong and upcoming recycling industry in and around the port</p> <p>Interesting port city for cruise vessels</p>	<p>Major dependency on fossil fuel (e.g. oil and coal) throughput that is expected to face major decline as a result of the energy transition</p> <p>Large throughput of ores, for which future is uncertain as a result of possible relocation of industry and gradual shift towards using more scrap in steel production</p> <p>Fierce competition with neighbouring German and Belgium ports for containers, as container ships require less water depth than tankers and bulk carriers, so that the deep water access channel provides less competitive advantage</p> <p>Vulnerable to the effects of climate change because of forced closure of barrier in entrance channel (during high water conditions) and poor navigability of river Rhine during extreme low water periods</p>
<p><i>Opportunities</i></p> <p>Create production and blending area for renewable fuels, including the production of synthetic fuels from imported/produced hydrogen and carbon capture and utilisation</p> <p>Create recycling and dismantling area for offshore rigs and ships</p> <p>Strengthen supply base for offshore energy production at sea</p> <p>Opportunity to increase short sea container transport</p> <p>Improve inland barge handling at deep-sea container terminals to increase the market share for deep-sea containers</p> <p>Develop aquaculture and fish farming in the port and at sea</p> <p>Expansion of cruise market for both maritime and inland shipping</p>	<p><i>Threats</i></p> <p>Major decline in fossil fuel throughput, which may result in the port losing up to 50% of its present cargo volumes</p> <p>Gradual decline in raw material throughput, e.g. ores in production of steel because of increased use of scrap</p> <p>Stagnation or decline in deep-sea container transport, as a result of aging of West-European population, reverse globalisation and effect of declining labour productivity growth and increasing inequality on GDP (affecting both production and consumption)</p> <p>Future loss of container cargo as a result of 3D printing; the effects are expected to be limited over next few decades</p> <p>Loss of market share because of climate change</p> <p>Threat of terrorist activity in the port</p>

### ***8.1 Liquid bulk and chemicals***

- Threat #1: Major decline in bulk fossil fuel throughput (mostly liquid fuels).
- Opportunity #1: Create production and blending area for renewable fuels.

Transition from fossil-based (crude) oil, oil products and chemical production to bio-based and renewables production will cause a shift in activities over next decades, but it will presumably take up until the upswing of the sixth Kondratieff wave until new industries become dominant. Space for development of new activities is therefore required from 2020 to 2040, with a further scale-up from about 2040 onwards, whereas areas of existing petrochemical industries will presumably not become vacant until about 2040 onwards. In fact, the port is likely to emerge as a consolidation area of fossil fuel-related activities in a declining fossil market because of its size and market position. This provides a strong base for an evolutionary transition of the (petro)chemical industrial cluster into a bio-based cluster, for which new activities can be located in the existing liquid and petrochemical areas. The existing port facilities can serve as renewable fuel production, storage and blending area. Renewable fuels can be exported in bulk carriers similar to the ones currently in use, and existing facilities for mineral oils can be used. When crude activities start to decline, the facilities can be converted into hydrogen-receiving facilities and connected to planned CO<sub>2</sub> pipelines for production of synthetic fuels such as hydrogen, methanol, ammonia and formic acid (whatever may become the standard). Intensified shipment of liquid bio-based materials by inland barges may be expected to locations where bio-materials are collected and processed into base materials in the hinterland. Produced fuels, either synthetic or bio-based, may be transported to the hinterland, exported or used for fuelling of sea ships.

### ***8.2 Dry bulk***

- Threat #1: Major decline in bulk fossil fuel throughput (with respect to solid fuels).
- Threat #4: Future loss of container cargo as a result of 3D-printing.
- Threat #5: Possible loss of market share because of climate change.

The most significant developments concerning dry bulk are the phasing out of coal as an energy source over the next few decades and for iron production within 30-40 years; a gradual shift from ore for steel production to intermediate products and scrap, a possible reduction in import (or increased export) of agri-bulk products because of declining population in Europe; and an increasing demand for new generation biofuels and biochemicals. Declining coal volumes require a consolidation of bulk handling activities. The free-coming space can be used for growing activities such as bio-bulk and scrap recycling. There is no clear indication as to when ore will phase out or as to the size of future ore carriers. New space may be required for handling of bio-bulk materials. Because the parcel size of bio-solids is smaller than for coal and ore minerals, smaller vessels can be expected.

### ***8.3 Containers***

- Threat #3: Stagnation or decline in deep-sea container transport.
- Threat #4: Future loss of container cargo as a result of 3D-printing.
- Threat #5: Possible loss of market share because of climate change.
- Opportunity #4: Opportunity to increase short sea container transport.
- Opportunity #5: Improve inland barge handling at deep-sea container terminals.

In contrast to previous scenarios, not all the space presently allocated for future expansion of container terminals may be required and some space could be used to accommodate new activities such as offshore construction and decommissioning in the new port area of the 2nd Maasvlakte. Improving the handling of inland barges can help to increase the overall market share of containers in the region, which is desirable in a stagnating market. This may be realised by developing dedicated quays for inland barges at or near the deep-sea terminals and by consolidating and reducing the number of empty depots. Similarly, feeder volumes can be increased by creating dedicated facilities at deep-sea terminals. There is also a potential to increase short sea container volumes. Short sea ships can be handled in the older port areas with smaller water depth, which are situated closer to the city and the hinterland. Ro-Ro ferries face fierce competition from continental container transport and benefit from locations at the port entry because of shorter sailing times.

#### ***8.4 Offshore construction and recycling***

- Threat #1: Major decline in bulk fossil fuel throughput (resulting in dismantling of offshore production units).
- Opportunity #2: Create recycling and dismantling area for offshore rigs and ships.
- Opportunity #3: Strengthen supply base for offshore energy production at sea (for both solar and wind).
- Opportunity #6: Develop aquaculture and fish farming in the port and at sea through installing offshore farm facilities.

There is a growing need for offshore facilities for the development of large offshore wind farms, decommissioning facilities for dismantling of North Sea oil and gas platforms and possibly for offshore solar farms over the next two to three decades. The 2<sup>nd</sup> Maasvlakte offers sheltered deep water space as well as dry and wet storage/assembly areas for these activities. Once in place, offshore supply bases can also be used for assembly of offshore fish farms, which, following the trends in Asia, may also become common on the North Sea over the next decades. There may be a further opportunity to create a dedicated ship dismantling facility at existing bulk locations that are confronted with a decline in throughput, especially in the older port areas close to existing shipyards and recycling companies. The recycling market will increasingly require additional space at metal scrap handling facilities.

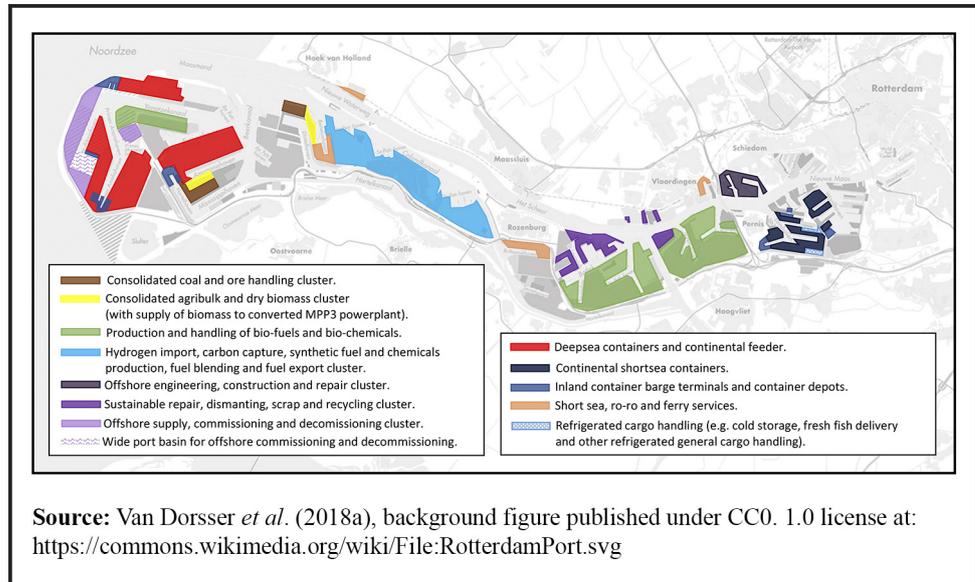
### **9. Step 6: towards a vision and port strategy**

These narratives indicate an urgent need for more efficient use of space in the port over the next few decades to seize opportunities and facilitate the development of new activities and port clusters. It is expected that port space will remain scarce over the next 20 years in spite of the recent expansion at the 2nd Maasvlakte. This is because the fossil industry is still expected to require another 20 years before phasing out, while space is already required for new activities that are gradually developing in line with the sustainability driver of the sixth K-wave. From a port perspective, it is desirable to support and facilitate these activities to ensure that the port is ready for the future around the year 2040 when new sustainable activities take over the dominant position of the old fossil industry and begin to scale up.

By matching the existing port infrastructure and the location of activities with the demand for space indicated by the narratives, one can schematise a possible clustering of future activities after the current transition period around the year of 2040. This can be seen in [Figure 2](#).

The sketch is drafted by the authors and does not necessarily represent the viewpoint of the PoR. It is included to illustrate how the proposed method could support decision-making.

**Figure 2** Proposed clustering of activities as suggested for the year 2040



## 10. Conclusions and further discussion

Foresight aims at identifying plausible developments to improve strategic decision-making. However, in today's complex rapid changing world, where trends in various spheres interact in increasingly unpredictable ways, it is difficult to gain insight into the inertia and expected direction of individual trends. This paper proposes a new integrated three-layered foresight framework and method for assessing various layers of megatrends based on their inertia or duration. The proposed theoretical framework shows that by analysing trends and key uncertainties in conjunction at the meta-level, and by placing them in a broader three-layered framework of megatrends, additional insight is obtained in the inertia and direction of long-term trends, aiming at sharper foresight for better decision-making.

The layers in the framework encompass:

- trends with a duration of over 100 years, which are relatively certain and can usually be assumed to continue for a few more decades;
- the so-called Kondratieff wave, or K-wave that relates to an about 50-years economic cycle and is closely linked to the pervasive economic-, technological- and social drivers of our modern industrialised world; and
- a plurality of megatrends that, on balance, seem to be closely linked to the movement and primary drivers of the K-waves.

The strength of analysing trends in conjunction at three distinct layers of inertia is that one becomes aware of the level of uncertainty at each individual layer. Also, by placing trends in a broader meta-perspective, the insights obtained from individual trends at the specific layers improve our understanding of the overall direction of the trends in the adjacent layers and vice versa.

The scope of this paper is limited to presenting the theoretical framework as a new integrated foresight approach, and illustrating, by means of a case study, that the method has potential to be used in practice. The next step is to investigate the applicability of the framework and method for other applications in practice, teaching and research, and to

provide a broader, more detailed and more nuanced assessment of trends and uncertainties.

Although the scope of this paper is essentially intended to present the theoretical framework as a new integrated foresight approach, its use has been illustrated for an actual case study for the Port of Rotterdam, where it was applied to gain insight into relevant trends and key uncertainties and to assess their expected impact on the port. This provided insight into plausible developments and their effect on future port business. The identified trends were “translated” into threats and opportunities for specific port activities while taking into consideration the strength and weaknesses of the port with respect to these activities. The result was a SWOT analysis in which threats and opportunities are based on an integrated framework of trends. Subsequently, a number of trend-based narratives were “distilled” from the SWOT. These narratives address the impact of plausible trends and key uncertainties on existing and potential new business activities. The narratives reflect the expected changes in the port arena and enable the port authority to think strategically and optimise their spatial planning for the development of future proof port industrial clusters.

For some port activities, such as the handling of fossil energy products such as coal and oil, the framework only confirms what is already known, i.e. that major decline in throughput can be expected, but for others, such as container transport, the results are more surprising. New insights in long-term economic growth and reverse globalisation hint at a decline rather than an ongoing increase of future container throughput. Other trends show opportunities for expansion of existing and new port clusters, such as for renewable offshore energy supply facilities; demolition and recycling of ships and offshore supply units; fish farming; and transfer, storage and processing of hydrogen, bio-fuels and bio-chemicals. This implies that the port authority could reserve less space for new container terminals and designate additional space to foster other promising opportunities.

The transitional forces driving these developments are clearly linked with the primary drivers of the K-waves, for which the framework provides insight into the direction that concerns a shift from globalisation to sustainability (and a partial reverse of globalisation from hyper-globalisation back to more sustainable levels of globalisation), and an ongoing trend towards increased levels of connectivity (i.e. a shift from ICT to IoT). This suggests that it is worth considering insights from K-waves in foresight. This is being increasingly acknowledged, but predominantly in relation to individual developments. The foresight method proposed in this paper aims at providing a more generic approach for incorporating K-waves.

Having presented the method, we hope that it will inspire others to apply the method on its own or in combination with other methods. The discussion on the use of the method for the PoR illustrates a practical application of the method on its own. Another suggestion may be to use the method in combination with the three horizons method for identifying the transformational processes.

## References

Adams, C. and Mouatt, S. (2010), “The information revolution, information systems and the 6th Kondratieff cycle”, *MCIS 2010 Proceedings, September 2010*.

Allians Global Investors (2010), “The sixth Kondratieff – long waves of prosperity”, *Analysis & Trends, January edition*.

Armstrong, J.S. (Ed.) (2001), “Principles of forecasting”, *A Handbook for Reaserachers and Practioners*, Kluwer Academic Publishers, Boston/Dordrecht/London.

Ayres, R.U. (1990a), “Technological transformations and long Waves – Part I”, *Technological Forecasting and Social Change*, Vol. 37 No. 1, pp. 1-37.

Ayres, R.U. (1990b), “Technological transformations and long Waves – Part II”, *Technological Forecasting and Social Change*, Vol. 37 No. 2, pp. 111-137.

- Brueckner, M. and Lederman, D. (2015), "Effects of income inequality on aggregate output", World Bank Policy Discussion Paper 7317.
- Brynjolfsson, E. (2014), *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*, 1st ed., W. W. Norton & Company, New York, NY.
- De Groot, B. and Franses, P.H. (2009), "Universal cycle periods", NRI Research Paper Series, No. 09-06, Nyenrode Research and Innovation Institute, Breukelen.
- De Haan, F.J. and Rotmans, J. (2018), "A proposed theoretical framework for actors in transformative change", *Technological Forecasting and Social Change*, Vol. 128, pp. 275-286.
- Fernald, J.G. and Jones, C.I. (2014), "The future of US economic growth", *American Economic Review*, Vol. 104 No. 5, pp. 44-49.
- Gordon, R.J. (2016), "The rise and fall of american growth", *The US Standard of Living since the Civil War*, Princeton University Press, Princeton and Oxford.
- Grübler, A. (1990), *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport*, Physica-Verlag Heidelberg.
- Grübler, A. and Nakićenović, N. (1991), "Long waves, technology diffusion, and substitution", *Review (Fernand Braudel Center)*, Vol. 14 No. 2, pp. 313-342.
- Haasnoot, M., Kwakkel, J.H., Walker, W.E. and ter Maat, J. (2013), "Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world", *Global Environmental Change*, Vol. 23 No. 2, pp. 485-498.
- Habegger, B. (2010), "Strategic foresight in public policy: reviewing the experiences of the UK Singapore, and The Netherlands", *Futures*, Vol. 42 No. 1, pp. 49-58.
- Hargroves, K. and Smith, M. (2005), "The natural advantage of nations: Business opportunities, innovation and governance in the 21st century", *The Natural Edge Project*, Earthscan, London.
- IMF (2019), "GDP data in current US\$", available at: [www.imf.org/external/datamapper/NGDPD@WEO/WEOWORLD](http://www.imf.org/external/datamapper/NGDPD@WEO/WEOWORLD), (accessed 13 October 2017).
- ITC (2020), "Three horizons framework. International training Centre", Foresight Toolkit, available at: <http://training.itcilo.org/delta/Foresight/3-Horizons.pdf>
- Juglar, C. (1862), *Des Crises Commerciales et de Leur Retour Périodique en France, en Angleterre et Aut États-Unis*, Ouvrage couronné par institute, Paris.
- Kondratieff, N.D. (1926), "Die langen wellen der konjunktur", *Archiv Für Sozialwissenschaft*, Vol. 56, pp. 573-609.
- Korotayev, A.V. and Tsirel, S.V. (2010), "A spectral analysis of world GDP dynamics: kondratieff waves, kusnets swings, juglar and kitchin cycles in global economic development, and the 2008-2009 economic crisis", *Structure and Dynamics*, Vol. 4 No. 1, available at: [www.escholarship.org/uc/item/9jv108xp](http://www.escholarship.org/uc/item/9jv108xp)
- Leonhard, G. (2016), *Technology vs. Humanity: The Coming Clash between Man and Machine*, Fast Future Publishing Ltd.
- Levy, J.S. and Thompson, W.R. (2011), *The Arc of War, Origins, Escalation, and Transformation*, The University of Chicago Press, Chicago and London.
- Lum, R.A.K. (2016), *4 Steps to the Future: A Quick and Clean Guide to Creating Foresight*, Vision Foresight Strategy, LLC.
- Martin, B.R. (1995), "Foresight in science and technology", *Technology Analysis & Strategic Management*, Vol. 7 No. 2, pp. 139-168.
- Miles, I. and Saritas, O. (2012), "The depth of the horizon: searching, scanning and widening horizons", *Foresight*, Vol. 14 No. 6, pp. 530-545.
- Modelski, G. and Thompson, W.R. (1996), *Leading Sectors and World Powers: The co-Evolution of Global Economics and Politics*, University of SC Press, Columbia, SC.
- Moody, J.B. and Nogrady, B. (2010), *The Sixth Wave: How to Succeed in a Resource-Limited World*, Vintage Books, Sidney.
- Murphy, D.J. and Hall, C.A.S. (2010), "Year in review – EROI or energy return on (energy) invested", *Annals of the New York Academy of Sciences*, Vol. 1185 No. 1, pp. 102-118.

- Naisbitt, J. (1982), *Megatrends, Ten New Directions Transforming Our Lives*, Warner Books.
- Oosterhaven, J. and Rietveld, P. (2003), "Transport cost, location and economy (in dutch: transportkosten, locatie en economie)", KVS paper, available at: [www.rug.nl/staff/j.oosterhaven/kvs\\_paper.pdf](http://www.rug.nl/staff/j.oosterhaven/kvs_paper.pdf)
- Oxford living dictionaries (2018), "Meta-level", available at: <https://en.oxforddictionaries.com/definition/metalevel> (accessed 20 November 2018).
- Sardar, Z. (2010), "Welcome to postnormal times", *Futures*, Vol. 42 No. 5, pp. 435-444.
- Sardar, Z. and Sweeney, J.A. (2016), "The three tomorrows of postnormal times", *Futures*, Vol. 75, pp. 1-13.
- Schumpeter, J.A. (1939), *Business Cycles – Volume I and II*, McGraw-Hill, reprinted in 1982 by Porcupine Press Inc.
- Sharpe, B., Hodgson, A., Leicester, G., Lyon, A. and Fazey, I. (2016), "Three horizons: a pathways practice for transformation", *Ecology and Society*, Vol. 21 No. 2, pp. 47, doi: [10.5751/ES-08388-210247](https://doi.org/10.5751/ES-08388-210247).
- Slaughter, R. (2009), "The state of play in the futures field: a metascanning overview", *Foresight*, Vol. 11 No. 5, pp. 6-20.
- Spies, P.H. (1998), "Millennial megatrends: forces shaping the 21st century", *Keynote address to the Annual Conference of the International Association of Technological University Libraries (IATUL), June 1st*, University of Pretoria.
- UN DESA (2017), "World population prospects: the 2017 revision", available at: <https://population.un.org/wpp/Graphs/>
- UNCTAD (2019), "Trade indicators in current US\$", available at: <http://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx>, (accessed 27-11-2019).
- UNDP GCPSE (2014), *Foresight as a Strategic Long-Term Planning Tool for Developing Countries*, UNDP Global Centre for Public Service Excellence, Singapore.
- Van Dorsser, C. (2015), "Very long term development of the dutch inland waterway transport system, policy analysis, transport projections, shipping scenarios, and a new perspective on economic growth and future discounting", Doctoral dissertation, TRAIL Thesis Series, T2015/8.
- Van Dorsser, C. Taneja, P. and Vellinga, T. (2018a), "Port Metatrends", Impact of long term trends on business activities, spatial use and maritime infrastructure requirements in the Port of Rotterdam, TU Delft and Smart-Port, available at: <http://resolver.tudelft.nl/uuid:2ae283d9-2acc-4abcd-97dd-bd67a4b1e07b>
- Van Dorsser, C., Walker, W., Taneja, P. and Marchau, V. (2018b), "Improving the link between the futures field and policymaking", *Futures*, Vol. 104, pp. 75-84.
- Van Duijn, J. (1977), "The long wave in economic life", *De Economist*, Vol. 125 No. 4, pp. 544-576, available at: <https://link.springer.com/article/10.1007/BF01221051>
- Van Duijn, J. (1983), *The Long Wave in Economic Life, Economic History Series, Reprinted in 2016*, Routledge, London.
- Van Duijn, J. (2007), *De Groei Voorbij, over de Economische Toekomst Van Nederland na de Booming Nineties*, De bezige bij, Amsterdam.
- van Wyk, R.J. (1984), "Panoramic scanning and the technological environment", *Technovation*, Vol. 2 No. 2, pp. 101-120.
- Volkery, A. and Ribeiro, T. (2009), "Scenario planning in public policy: understanding use, impacts and the role of institutional context factors", *Technological Forecasting and Social Change*, Vol. 76, pp. 1198-1207.
- Walker, W.E., Haasnoot, M. and Kwakkel, J.H. (2013), "Adapt or perish: a review of planning approaches for adaptation under deep uncertainty", *Sustainability*, Vol. 5 No. 3, pp. 955-979.
- Walker, W.E., Marchau, V.A.W.J. and Swanson, D. (2010), "Addressing deep uncertainty using adaptive policies: introduction to section 2", *Technological Forecasting and Social Change*, Vol. 77 No. 6, pp. 917-923, doi: [10.1016/j.techfore.2010.04.004](https://doi.org/10.1016/j.techfore.2010.04.004).
- Watson, R. (2013), Blog, available at: <http://toptrends.nowandnext.com>, 2013/02/14 (accessed 11 February 2019).
- Wayland, R. (2015), "Strategic foresight in a changing world", *Foresight*, Vol. 17 No. 5, pp. 444-459.
- West, M. and Harrison, J. (1999), *Bayesian Forecasting and Dynamic Models*, Springer, New York, NY.

Wilenius, M. and Kurki, S. (2017), "K-Waves, reflexive foresight, and the future of anticipation in the next socioeconomic cycle", In Poli, R. (Ed.) *Handbook of Anticipation*, Springer, Cham.

Wilenius, M. (2015), "The next K-Wave and the challenge of global democracy", *Foresight*, Vol. 17 No. 1, pp. 35-53.

Z-Punkt GmbH (2020), *Megatrends, the Foresight Company*, Köln, available at: <http://81.47.175.201/flagship/attachments/megatrends.pdf> (accessed 10 July 2019).

## Further reading

Voros, J. (2003), "A generic foresight process framework", *Foresight*, Vol. 5 No. 3, pp. 10-21.

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