PBL Netherlands Environmental Assessment Agency

Yangtze & Rhine river basins 1950–2050

Mapping and comparing urbanisation, environmental pollution, climate adaptation and decarbonisation

Colophon

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Arjan HARBERS (PBL), Jan BAKKES (PBL), Charlotte LE VAY, LYU Hongliang (CAUPD) and JIANG Like (CAUPD)

Contents

Summary

This report investigates the relevance and scope of a future in-depth analysis of consecutive environmental development issues in the economic regions of the Yangtze and Rhine river basins, for the 1950–2050 period. The findings on the mandated questions of relevance and scope are presented below.

1. **Although, at first glance, the Yangtze and Rhine river basins appear very different, similar issues arise in these basins, such as regarding pollution, biodiversity conservation, urbanisation, climate adaptation and decarbonisation.** In the Yangtze Basin, these issues pose both challenges and opportunities that are compressed in time, relative to those in the Rhine Basin.

   The results from this study confirm the initial observation from a CCICED Round Table, held in 2019, about a comparison between these river basins can be mutually interesting for regional planners, policymakers and other stakeholders.

   Naturally, there are differences between the two river systems, notably in their overall size, the presence of dams (many in the Yangtze Basin and hardly any in the Rhine Basin), and in their governance system. The wider Rhine Basin has urban regions that have changed profoundly in the 20th century, whereas urbanisation in the Yangtze Basin only began to increase greatly after 1990. By and large, the combination of differences and commonalities, and the different timeframes in which these changes took place only add to the value of making an in-depth comparison.

2. **The Rhine and Yangtze river basins are good examples for a comparison through a time-and-space 'lens', where climate adaptation, urbanisation, decarbonisation, environmental pollution and biodiversity conservation and degradation come together in comprehensive ecosystems.**

   Regarded through this time-and-space lens, especially using mapping, a river basin is a good area to study in real life, because of the various underlying concerns of a more general nature. These comprise the need for transitions that benefit all stakeholder groups and the difficulty to mobilise broad support for addressing long-term issues, which often require collaboration between many parties in connection to the cultural economic and ecological significance of the river.

These concerns also include trade-offs that feature in both basins in relation to the coastal zones (e.g. related to dams and canalisation), deployment of alternative energy sources (e.g. biomass), and various rebound effects.

3. **One of the changes that can be witnessed in these river basins, within their respective contexts, is the transition from a production economy to a service economy.**

   This includes the ambiguities about whether the old style economy will largely be replaced by the service economy and the related new skill set, consumer behaviour and urban form, or will just be added to it. The transition also includes key choices — past, current and future — about planning strategies and long-term investments with a lasting effect. Importantly, these choices relate to urban form and the future of fossil-based industries, such as refineries, which have developed within both basins.

4. **Boundaries of large river systems rarely coincide with administrative boundaries, making river systems the archetypical situation where collaboration between larger groups of stakeholders and administrations is essential to manage the system and its resources — water volume, silt, water quality, biodiversity.**

   The Yangtze and Rhine river basins are no exception, as they span multiple jurisdictions and areas of competence. The basins differ in governance and legal systems, with the River Commissions and River Chiefs in China, as well as the Yangtze Law from 2021, and the long-standing International Rhine Commission and Rhine Treaty in Western Europe. This creates a rich basis for comparison.

5. **Urbanisation processes and the related spatial, economic and ecological strategies hold distinctive information on the two basins as comprehensive ecosystems.**

   The development strategies of Shanghai and Rotterdam are in a league of their own, with respect to urban development, economic orientation and connections, low-carbon energy, adaptation to climate change, involvement of stakeholders, and their aim for a 'fair transition'. Many other cities and industries in these two basins also have a story to tell, including how they managed comprehensive change over the past decades, a few of which are very briefly summarized in this study.

6. **Amongst the main findings in this study are the pervasiveness and long-term effects of intensive agriculture.**

   These findings were based on assessments on the Rhine Basin, which are very likely to also apply elsewhere. The long-term effects result from legacy pollution caused by nutrients, in addition to other, better-known effects, such as those caused by urban spatial patterns, power plants and refineries, and educational and demographic trends.

7. **There are many data-related obstacles for the envisaged in-depth comparison, but these are probably not prohibitive.**

   Most obstacles are of a technical nature and relate to the different demarcations and scopes involved (e.g. governance, geographic and economic contexts). Proper allocation of analytical capacity may solve this problem to the extent required for case studies, but this will take some time. A second category of obstacles seems to be formal access to specific data, both in China and in Germany (because of Germany's federal structure of government). It is thought that, at least in China, carrying out the envisaged comparative study under the aegis of CCICED, with a modest budget for data extraction, would greatly help.

Guide to the Reader

Purpose

This is a preparatory study. It investigates the relevance and feasibility of an in-dept comparison of environmental challenges and opportunities in the economic area of the Yangtze and Rhine river basins. It should provide a better understanding of the mechanisms and the type of research and data needed to carry out a full study on the economic area of the Yangtze and Rhine river basins.

Origins of this project

This study follows from the Round Table as part of the Task Force Green Urbanization and Environmental Improvement for the China Council for International Cooperation on Environment and Development (CCICED), held in The Hague on 8 April 2019. Participants of the Round Table were fascinated by the observation that the basins involve very similar environmental and development issues. Although developments in the Yangtze Basin are much more rapid that in the Rhine Basin. This compression in time both brings greater opportunities for effective forward-looking strategies and carries larger risks of lock-in effects.

Therefore, a comparison between the two basins, both over the past decades and in projections and policies on the future, is thought to be a rich source of mutual inspiration for decision-makers and stakeholders. Analysis from this perspective could inform strategic planning of interventions, such as on decarbonisation, urban infrastructure and adaptation to climate change. It could be of potential use to many other river basins, especially those with a highly concentrated economy in their delta.

The CCICED Round Table was hosted by the Dutch Ministry of Infrastructure and Water Management and PBL Netherlands Environmental Assessment Agency, chaired by PBL's Director-General, Professor Hans Mommaas, and Professor Li Xiaojiang, former President of the China Academy of Urban Planning and Design (CAUPD). Professor Hans Mommaas and Professor Li Xiaojiang are the Executive Vice Chairs of the Task Force.

After the Round Table, PBL and CAUPD proceeded to jointly develop their ideas further, which were enthusiastically supported at a subsequent meeting alongside the Annual General Meeting of CCICED, on 3 June 2019 in Hangzhou. PBL offered to conduct the study in this report, further exploring relevance and feasibility, especially in terms of data. CAUPD pledged to support the study.

Scope

This report supposes, naturally, a systematic and comprehensive view on managing urbanisation, environmental protection, decarbonisation and climate adaptation in the river basins. The time span of the analysis — approximately a century — makes this inescapable, because of the many connections between developments. This, too, was underlined at the Round Table. Therefore, the report touches on several key sectors, such as those of energy sector and agriculture; on developments with a long-lasting presence, such as education and urbanisation; and on aspects beyond the biophysical, such as cultural value and governance.

In particular, the Round Table highlighted the untapped potential of closer coordination between environmental and spatial planning policies. That is why we arranged the body of this report along four topics: urbanisation, environmental protection, climate adaptation and decarbonisation.

This report addresses these topics only to the extent necessary for reaching conclusions on the relevance and feasibility of the envisaged future study. For an in-depth discussion, the reader may wish to consult further literature.

Geographical delineation

For this comparative research, the Meuse and Scheldt Basins are included in the Rhine Basin, in most observations, because they are intertwined with the Rhine Delta. Many data of an economic and demographic nature are not available, separately, on the scale of river basins, which is why, in statistical comparisons, we often use the data on the six countries that have a large area in the Rhine catchment (i.e. Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland).

For the Yangtze, we examined the area of the Yangtze River Economic Belt (YREB), comprising of 11 provinces (Shanghai, Jiangsu, Zhejiang, Hubei, Chongqing, Hunan, Sichuan, Anhui, Jiangxi, Guizhou and Yunnan) that surround the river and where most of the relevant economic activity takes place. The YREB is one of the strategies for the sustainable development of the Chinese economy (see Figure 1 and 2).

Delineation in time

As far as time is concerned, we took a 100-year period, looking back to 1950 and ahead to 2050. This provided insight into the various experiences with the approach to environmental and spatial planning issues in the river basins, which differ from each other, both administratively and economically. This period is also historically and contextually significant in Western European and Chinese contexts. In Europe, the industrialisation began far before the 1950s, and began to decline after the 1960s and 1970s, whereas in China, it grew rapidly over the last decades of the 20th century and is continuing to grow, today, albeit at a slower pace.

Structure

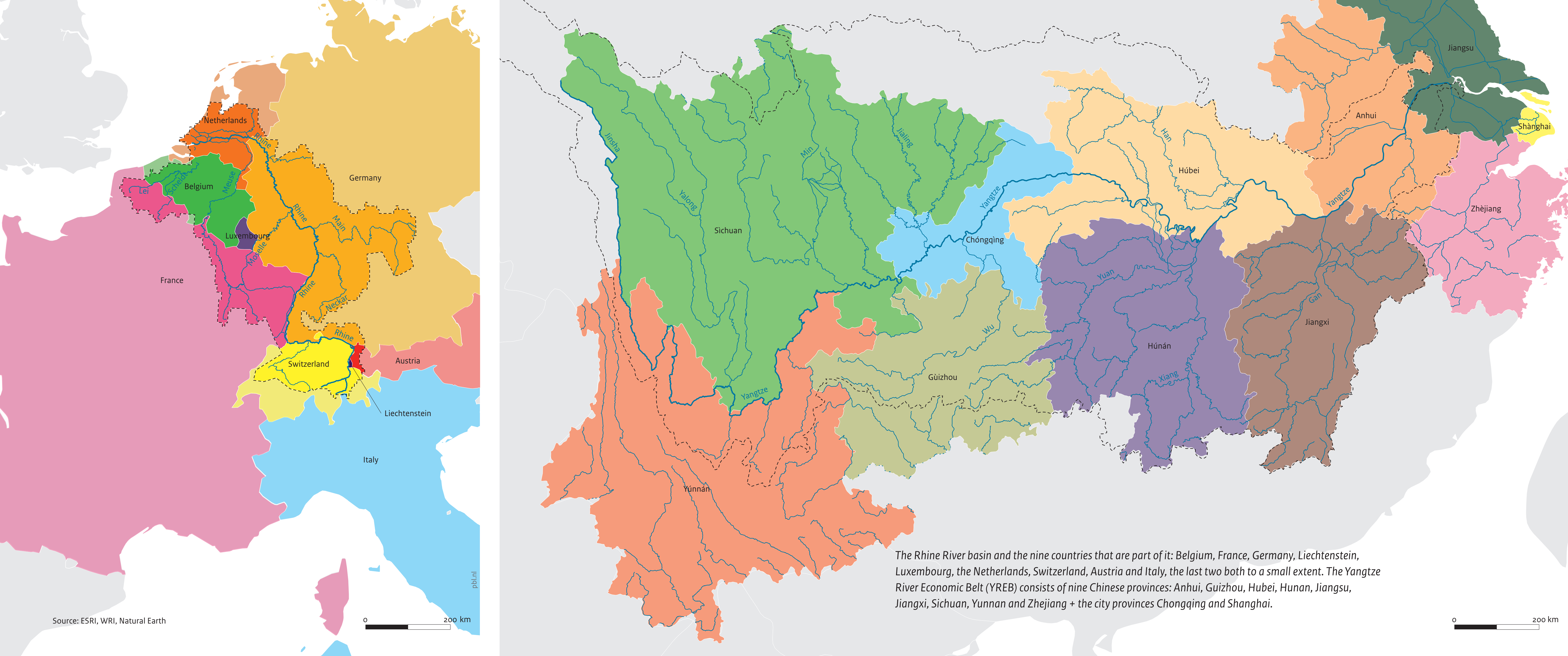
Chapter 1 provides a brief overview in space and time of river basins, arranged by urbanisation, water works and agriculture, as origins for environmental and spatial issues. Chapter 2 introduces the two basins in terms of facts and figures. Chapters 3, 4, 5 and 6 each focus on one of the large cluster of policy issues of urbanisation and urban form; pollution and biodiversity; climate change adaptation; and decarbonisation of economic activities. In each of these four chapters, both basins are covered. Illustrative cases are highlighted in boxes in each of these chapters. Chapter 7 summarises findings, lists observations and draws conclusions with a view to relevance and scope of the envisaged future study.

Figure 1
Location of the Rhine river basin and the Yangtze River Economic Belt (YREB)

The location of the Rhine River basin in Western Europe — in blue, including the basins of the Meuse and Scheldt; in magenta, the comparison to the Yangtze River Economic Belt (YREB). The actual, physical border of the Yangtze River basin is the dashed line.
The Yangtze River basin is obviously much larger than the Rhine River basin.

Source: WRI, Natural Earth

Figure 2
Rhine, Meuse and Scheldt river basins and Yangtze River Economic Belt provinces



Source: ESRI, WRI, Natural Earth

The Rhine River basin and the nine countries that are part of it: Belgium, France, Germany, Liechtenstein, Luxembourg, the Netherlands, Switzerland, Austria and Italy, the last two both to a small extent. The Yangtze River Economic Belt (YREB) consists of nine Chinese provinces: Anhui, Guizhou, Hubei, Hunan, Jiangsu, Jiangxi, Sichuan, Yunnan and Zhejiang + the city provinces Chongqing and Shanghai.

Foreword

It is a long-standing insight that wise and effective management of large socio-environmental systems needs to be comprehensive and integrated. Climate change only adds to this. The river-basin scale is a logical unit for managing such complexity and good for studying experiences in integrated management.

River basins stretch from the mountains to the sea. Water flows towards the sea, goods and fuels are transported upstream and downstream. Many human settlements have their economic and cultural roots along a river. The dynamics in both the Yangtze and Rhine basins include urbanisation and economic changes, and sustainability issues include those of pollution, landscape and biodiversity management, and the need to decarbonise. In some river systems, the issues include decision-making on dams for hydro-electricity and all the associated trade-offs and perhaps even larger energy systems in the future. Climate change not only adds to all these issues, often with flooding and droughts both becoming more frequent, but also complicates and exacerbates all existing issues.

At the Round Table on Green Urbanization and Environmental Improvement for the China Council for International Cooperation on Environment and Development (CCICED) in The Hague on 8 April 2019, a core observation was that, by and large, China and Western Europe experience similar challenges and opportunities in the domains of urbanisation and river basin management. But they develop from different starting points and at different speeds. The net effect is that successive planners and decision-makers in, for example, the Yangtze River Basin, must address the same cascade of issues as in, for example, the Rhine basin — but compressed in time.

In our view, this core observation in particular is worth further analysis. Comparing experiences, as well as foresight, between two basins, such as those of the Yangtze and Rhine, could yield useful lessons for strategic management in both parts of the world. This would be especially valuable to the timing of interventions, investment changes and the need to leave no one behind. The lasting effect of urban spatial patterns comes to mind, longevity of installations in the energy industry and the time it takes to turn around the economy of a region, including its identity.

Therefore, this report was initiated as a first exploratory step towards in-depth comparison. Comparison of the rivers Yangtze and Rhine, even though they differed in overall length. Both represent major economic zones within their own context, thus presenting especially pertinent cases of balancing the growth of urbanisation and economic activity with sustainable practices and protecting nature and biodiversity. With their urban agglomerations included, they represent 'delta economies' of global significance.

The participants of the Round Table underscored that, for example, reducing environmental pollution, achieving climate adaptation and decarbonisation, as well as innovation of economic sectors and regions, are all interrelated within river basins. This is why it would be environmentally and socially ineffective to address one aspect without the others and why sectoral challenges should be more integrated. However, practice on the ground leaves much to be improved. According to the Round Table, much can be gained from better coordination of spatial planning policies and environmental policies. We subscribe to this opinion and expect the future study, of which the current report explores the relevance and feasibility, to produce even more case material and how-to lessons.

Covid circumstances have slowed down completion of the present report. Nevertheless, we expect that it is very timely, now that the CCICED is considering its next five-year cycle of work (2023–2027) and is initiating work on managing river basins in times of climate change, in close relation with its urban research agenda. We hope that the current report and the envisaged comparison project will further enhance the opportunity for mutual learning between China and the other CCICED members, in examining best practices and avoiding pitfalls.

Jan Hendrik DRONKERS (SG Ministry of Infrastructure and Water Management), CCICED Member

and

André VAN LAMMEREN (Deputy DG PBL Netherlands Environmental Assessment Agency)

River-basin-related tasks for environmental and spatial planning policies

1

与河流流域环境与空间规划政策密切相关的任务

Both China and the Netherlands face many challenges in relation to the environment and spatial planning. Both countries are highly urbanised and have to contend with environmental pollution. The biodiversity has declined sharply and there are major challenges concerning climate adaptation and decarbonisation. The river basin is a suitable scale for tackling these issues in conjunction. We looked to what the main challenges are on this scale, at the level of a river basin, and how are they interrelated in time and space.

1.1 River-basin-related tasks, coherent in time and space

Rivers are traditionally the arteries of both the ecosystem and the economy. To control trade, human settlements were often founded along the riverbanks, in places where the river could be crossed. These areas were also logical locations for urbanisation and industrialisation, as they provide fertile soil, fish, ample fresh water and a means of transport. Road and rail infrastructure also traditionally run parallel to rivers, as height differences are smaller. Thus, rivers and their tributaries often formed the backbone of urbanisation. Industrial processes, which are largely responsible for greenhouse gas emissions, are located along rivers and in harbours to serve shipping transport and provide cooling water.

Hydropower plants are, of course, inextricably linked to rivers and, thus, have an impact on ecosystems further downstream. In addition, wastewater pollution also has a major impact on biodiversity and the quality of the local environment. Finally, flood risks along rivers are related, amongst other things, to interventions in water management upstream. The frequency and intensity of these interventions are increasing due to climate change.

All this makes the river basin a logical area for arriving at a coherent policy to address the challenges of biodiversity, pollution, urbanisation, decarbonisation, and climate adaptation. These challenges are, after all, strongly interwoven and each has a spatial and a temporal component, as any approach will have consequences elsewhere and in the future. A purely sectoral approach may lead to trade-offs that are insufficiently considered in decision-making. And a short-term approach can lead to future needs not proving appropriate later on.

The approach to environmental and spatial planning issues not only affects the local environment, but the location is also a precondition; after all, addressing a location-specific issue may generate synergy by combining it with other issues nearby. Moreover, the order in which issues are tackled is important in achieving such synergy.

Climate change will often intensify existing environmental and spatial planning tasks and make them more complex: Some examples: A rise in temperature and more extreme precipitation events will most likely increase agricultural run-off, affecting water quality; drought lowers water levels and increases concentrated pollution. Flooding carries polluted water and materials ashore and subsequently to the rivers.

Along the Rhine, there are many international agreements that aim to improve water quality and manage water quantity. A more integrated river basin management has been worked on in China for quite some time, as well (Wang et al., 2007).

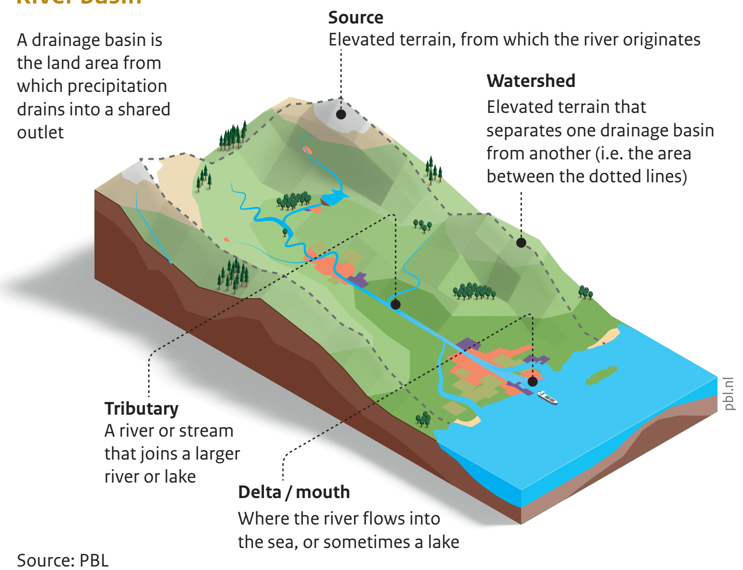
1.2 River basins: key concepts

A river basin is primarily a hydrological unit. All precipitation in this area will end up in the same river, sometimes via its tributaries, and goes towards the sea, with the exception of the water that evaporates. Elevated parts, such as mountain ridges, act as boundaries. Thus, the water within these boundaries flows into the central river or its tributary. Many activities within the boundaries affect the river and are therefore interrelated (Figure 3).

The hydrological boundaries of river basins are rarely the same as the administrative borders. Large river areas are predominantly transboundary. In these areas, neighbouring countries often rely on one another for fresh water, good water quality, biodiversity, fish, and sediment flow. In transboundary rivers, the impacts of pressures upstream are felt by countries downstream. This transboundary character makes river basin policies more difficult, but not less necessary.

River basins, typically, are also connected in economic and logistical ways, as well as in social and cultural terms. For example, a large part of the Yangtze basin is referred to as the Yangtze River Economic Belt. This report uses the term river basin primarily in the sense of a drainage basin, while considering its other dimensions, too, when relevant.

Figure 3
River basin



Source: PBL

Schematic of a river basin, stretching from the mountains to the sea, encompassing nature, agricultural land, urbanised areas, industry and ports.

1.3 Consequences of urbanisation, industrialisation, water works and agriculture

Many environmental issues are the result of urbanisation, industrialisation, water works and agriculture. Based on these causes, here, we describe the policy tasks that have a direct relationship with river basins and the way the mechanisms involved work. Chapters 3 to 7 describe the developments per issue in the Yangtze and Rhine river basins and the related policy applied.

1.3.1 Consequences of urbanisation and industrialisation for the environment and climate adaptation

Cities generate around 80% of global Gross Domestic Product (GDP) and are the source of a large share of greenhouse gas emissions (World Bank, 2021). The global population continues to grow, and an increasing number of people will live in cities. However, this population growth and urbanisation places great pressure on natural resources and quality of urban life. The growth in cities and infrastructure is displacing flora and fauna and cuts through the various habitats.

The increase in greenhouse gases in the atmosphere, originating mostly from cities, leads to climate change with far-reaching consequences for the human environment. Cities are particularly sensitive to the effects of climate change, because of their concentration of people, infrastructure and goods and, in large parts of the world, an ageing population. Rising temperatures can lead to urban heat islands, increase the frequency of extreme weather events, both on the wet and the dry side, and therefore also increase flood risks, amongst many other things. Over the long term, sea level rise will complicate matters for urban areas near the coast.

There are several other effects of urbanisation, particularly in the context of river basins:

- Urban, agricultural, and industrial expansions affect land-use change that, in turn, directly affects river systems. Ponds and wetlands are drained, filled in or raised to create land for urban development. Tributaries are filled in or built-up; **Floodplains** along the river are reclaimed by the installation of embankments for flood protection. As a result, the river loses its capacity for handling high water levels, water storage and conveyance. And shallow areas along the coast and at the river mouth are reclaimed to provide land for urban expansion. Because of all these interventions, the water system is deprived of its retention capacity and wetland ecology (CCICED 2021).
- The global demand for sand, gravels and silica for construction materials has grown considerably since the 1990s, as a result of economic and urban growth (CCICED, 2021). **Sediment mining** from rivers leads to changes in riverbed topography, in hydrologic and hydraulic regimes, in ecosystems and disperses contamination (CCICED, 2021).
- **Surface sealing**, through road and housing construction and infrastructure, causes large, impenetrable surfaces in cities. This affects run-off rates and may lead to flash flooding and a decrease in natural recharging of aquifers (Bertrand-Krajewski, 2020).
- **Air pollutants**, originating particularly from industry, road traffic, households, agriculture, and energy production, may pollute precipitation and run-off and, thus, also water quality.
- **River pollutants** consist of nutrients, a wide variety of toxic substances, pharmaceuticals, plastics, and waste. They, for example, originate from urbanised and industrialised areas, harbours and shipping, and are distributed by the river outflow into lakes, the near-coastal zone and the oceans. In the oceans and coastal seas, these pollutants adversely affect biodiversity in many ways, throughout the entire food chain. In addition, riverbeds also contain legacy pollutants that, for decades, may continue to have an effect downstream.
- **Soil subsidence**, as a result of large and often unregulated groundwater abstraction.

1.3.2 Consequences of agriculture for the environment

New agricultural land is often created at the expense of nature areas and biodiversity. In addition, the following mechanisms apply specifically to river basins with regard to the environment and biodiversity:

- **Soil erosion**: Conventionally ploughed agricultural fields are eroding much stronger than natural soil does (Montgomery, 2007), significantly increasing sediment fluxes downstream and increasing run-off.
- In addition to the pollution due to urbanisation and industry, there is also water that is polluted by faecal matter from intensive livestock farming and over-fertilisation of arable land. If these **nutrients** end up in the groundwater and in surface waters, this has consequences downstream. Large concentrations of nutrients induce algal blooms and weed growth over large areas, with negative effects on ecosystems and the economy. Extensive weed growth may find its way onto beaches and harm the tourism industry (CCICED, 2021).

1.3.3 Consequences of water works for the environment and climate adaptation

Human intervention in the water system may lead to degradation of ecosystems and river dynamics:

- The construction of, for example, dams, canals, sluices, and locks changes the watercourse. The potential advantages of hydropower over carbon-emitting power sources, as well as other uses of **river dams**, such as irrigation, flood control and water supply management, are clear. However, dams stand out amongst the main river stressors with significant impacts on river systems (CCICED 2021). Dam water retention and water release for hydropower production often conflict with ecosystem requirements downstream.
- **Sediment trapping** in reservoirs directly affects downstream river dynamics and ecosystems, and influences coastal processes, increasing coastal flood risks.
- **Dredging** may also induce changes with respect to local flow and sediment flux, thereby influencing factors, such as channel deepening and changing salinity intrusion in coastal regions.
- Water is often **diverted** to make up for shortages, prevent flooding, improve water quality, or generate electricity. In addition, rivers can be interconnected to create more shipping routes. This may affect biodiversity as invasive species are brought along the new routes. Invasive animal and plant species are a significant pressure on river ecosystems, affecting biodiversity and ecological structure.

1.4 Environmental and spatial planning challenges in the Yangtze and Rhine basins

The mechanisms and the dependencies between the various sectoral policy tasks introduced above, give rise to a comparison between river basins. The following chapters analyse the impact of these mechanisms on the Rhine and Yangtze river basins. There are, of course, more mechanisms that lead to environmental improvements, but they do not directly relate to the dynamics of river basins.

A comparison is made between the Rhine and Yangtze river basins over the 1950–2050 period, from a spatial perspective, according to the following themes: urbanisation, biodiversity and environmental pollution, climate adaptation and decarbonisation.

2 Introducing the Rhine and Yangtze basins

莱茵河与长江流域简介

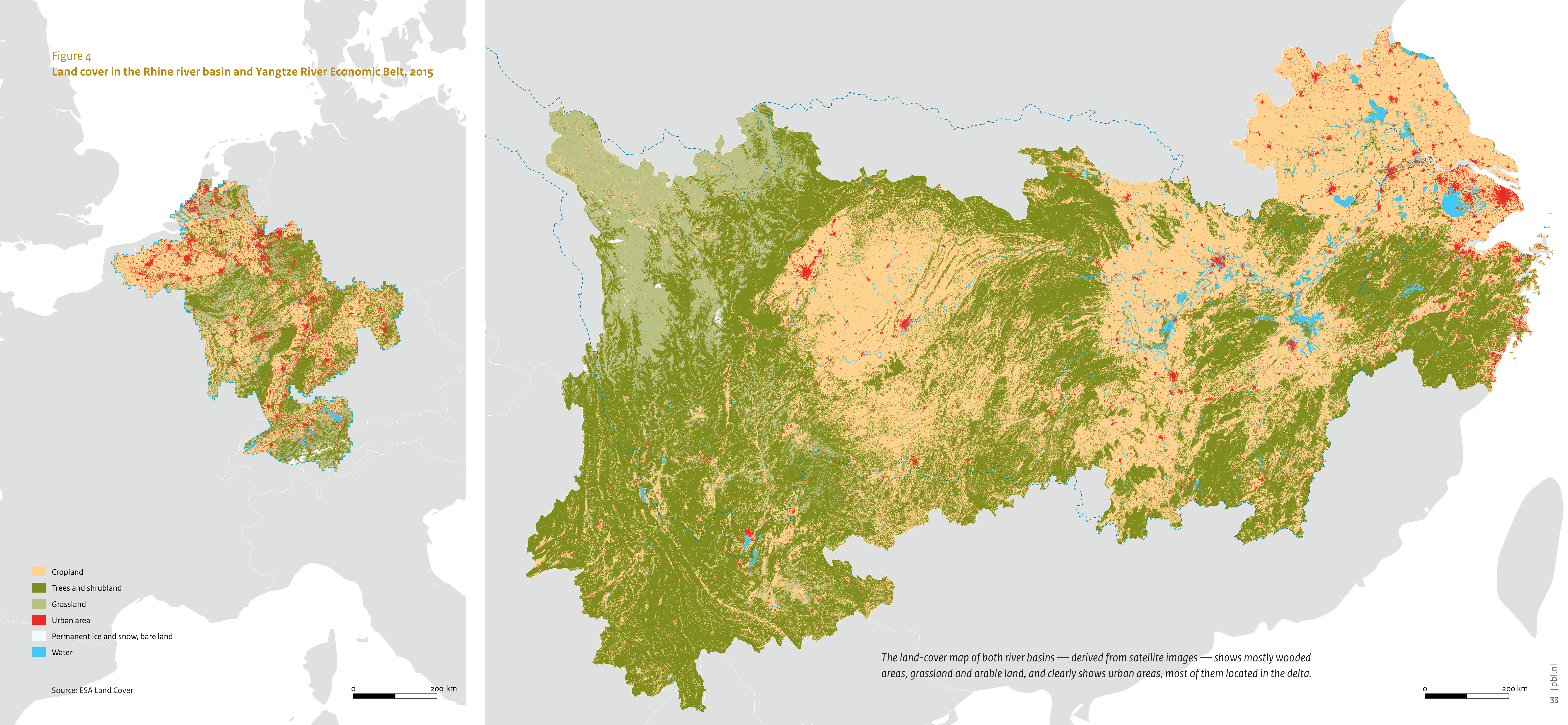
The Rhine and Yangtze river basins differ enormously with respect to their dimensions, but their economic dynamics are very similar.

The Rhine river flows from south to north, beginning in the Swiss Alps, through the central uplands and plateau regions (notably in the French and German parts of the Rhine and finally in the Dutch lowlands to the coastal plains. It passes urban clusters, such as Frankfurt/Rhein-Main and Rhein-Ruhr in Germany and the Randstad in the Netherlands. The river basin also includes Liechtenstein, a major part of Luxembourg, and minor parts of Austria, Italy and Belgium. The river measures a total length of about 1250 km, with a drainage area of about 185,000 km2. The Rhine's main tributaries are the Main, Moselle and Neckar.

The Yangtze is the largest river in Asia, measuring 6300 km, with a drainage area of 1,808,500 km2. The Yangtze river flows from west to east, from the Tibetan plateau, to the western-central hinterland, which is experiencing major economic and industrial growth along with increasing rates of urbanisation, to the delta (Shanghai area) which is an established and highly developed region. The Yangtze passes the Chengyu urban agglomeration (Chengdu and Chongqing), the Yangtze Middle Urban Agglomeration (Wuhan) and the Yangtze Delta Urban Agglomeration (Shanghai, Hangzhou and Ningbo). The Yangtze's main tributaries are the Han, Yalong, Min, Jialing, Wu, Jinsha, Xiang, Yuan and Gan.

As shown in Figure 4, it is evident that, despite being contained in one country, the Yangtze river basin drains a much larger area of land than that of the Rhine. Both the Yangtze and Rhine river basins contain mainly croplands and forests. The urbanised areas are relatively small compared to those containing nature and agriculture. The agglomerations in the Yangtze river basin are much larger than the ones along the Rhine (Table 1). However, both river basins are economically important constituents of their wider regions.

Figure 4
Land cover in the Rhine river basin and Yangtze River Economic Belt, 2015



Source: ESA Land Cover

The land-cover map of both river basins — derived from satellite images — shows mostly wooded areas, grassland and arable land, and clearly shows urban areas, most of them located in the delta.

Table 1

	Yangtze			Rhine/Meuse/Scheldt		
Population (river basin)	400		million inhabitants (2018)	77		million inhabitants (2018)
Main river length	6300		km	1250		km
River basin size	1,808,500		km²	242,123		km²
Discharge (av) of main river	900		km³/yr	72.5		km³/yr
Major cities	Shanghai	24.2	million inhabitants (2018)	Brussels	1.2	million inhabitants (2018)
	Chengdu	16.3		Cologne	1.1	
	Wuhan	11.1		Amsterdam	0.8	
	Hangzhou	10.4		Frankfurt	0.7	
	Chongqing	8.7		Dusseldorf	0.6	
	Nanjing	8.5		Rotterdam	0.6	
	Ningbo	8.5		Stuttgart	0.6	
	Changsha	8.2		Antwerp	0.5	
	Hefei	8.1		Duisburg	0.5	
	Kunming	6.8		Strasbourg	0.4	
	Nanchang	5.5		Zurich	0.4	
	Guiyang	4.9		Basel	0.2	
Major urban agglomerations	Yangtze Delta urban agglomeration	153	million inhabitants (2018)	Metropolitan region Rhein–Ruhr	12.9	million inhabitants (2018)
	Yangtze middle urban agglomeration	125		Randstad	8.2	
	Chengyu urban agglomeration	106		Metropolitan region Frankfurt/Rhein-Main	5.8	
Main sea ports	Shanghai	42,010	Container traffic (in thousand TEUs) in 2018	Rotterdam	14,510	Container traffic (in thousand TEUs) in 2018
	Ningbo-Zhoushan	26,350		Antwerp	11,100	
	Taicang	5,071				

Urbanisation in the Yangtze and Rhine river basins

3

莱茵河及长江流域城镇化

This chapter explores the relationship between urbanisation and the Yangtze and Rhine rivers. It maps the urbanised areas, economy-related topics and infrastructural networks and discusses how they relate to the river basins. It also shows the demographic trends and their impact on urbanisation, and addresses the question of how urbanisation relates to environmental planning, climate adaptation and decarbonisation?

3.1 An increasing, aging population living in the deltas and along the rivers

Rivers, historically, have been attracting human settlements because they are a source of fresh water and fish and as a means of transportation. In addition, the surrounding fertile land is particularly conducive to agriculture. During the period of industrialisation in both Western Europe and China, the urban areas expanded extensively . In the 20th and especially 21st century, although the centrality of the river for economically sustaining cities diminished, cities remained and expanded along the banks of rivers as a matter of path dependency.

In Europe, during the industrial revolution, cities located next to major rivers and ports, and those close to natural resources (such as coal, iron and water), became especially successful. In the Yangtze River Economic Belt, most major cities are found along the rivers, as well.

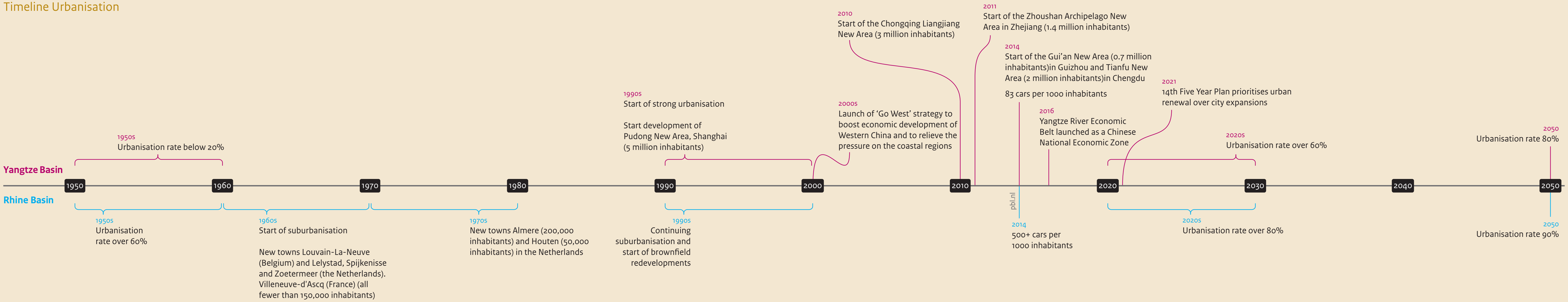
China's population, today, is 2.5 times that of 1950 and is expected to continue to increase to 1.4 billion by 2030, after which it will start to decline.

The European Union (0.5 billion people in 2020) has seen a more moderate population growth. A slight decrease will start after 2035. By then, in both in the EU and China, an increasing share of the population will be over 65 (Figure 5), with specific demands on housing and being more vulnerable to pollution. In China, the sharp decrease in the working-age population, relative to the total population, will mean an economic change in perspective.

Since the 1980s in China, due to the availability of jobs in cities, people have increasing left the countryside and moved to the cities. This has caused a massive urban expansion with high population densities. In the past three decades, 260 million migrants moved from rural areas to the cities, and 40% of new urban residents became urbanites because near-by cities expanded and encompassed the rural areas they were living in (World Bank, 2014).

The urbanisation rates in the Rhine countries have been increasing to over 70% and this increase is expected to slightly continue in the coming years. The Chinese urbanisation rate is expected to increase from 12% in 1950 to 80% by 2050 (see Figure 6). The Yangtze River Economic Belt today has an

Timeline Urbanisation



Source: PBL

urbanisation rate of around 57%. In most of the provinces along the Yangtze, the urbanisation rate is above the Chinese average and, on the YREB, it is growing faster than the national average.

Urbanisation rates differs between the Rhine and the Yangtze (Figures 7 and 8), with higher rates downstream and lower rates upstream. Upstream, there are some mega cities along the Yangtze (Wuhan, Chongqing and Chengdu). Along the Rhine, population densities are great in the Randstad, Rhein Ruhr and Brussels. Although urbanisation rates are lower in the Yangtze Basin, the population density is generally much greater than in the Rhine Basin.

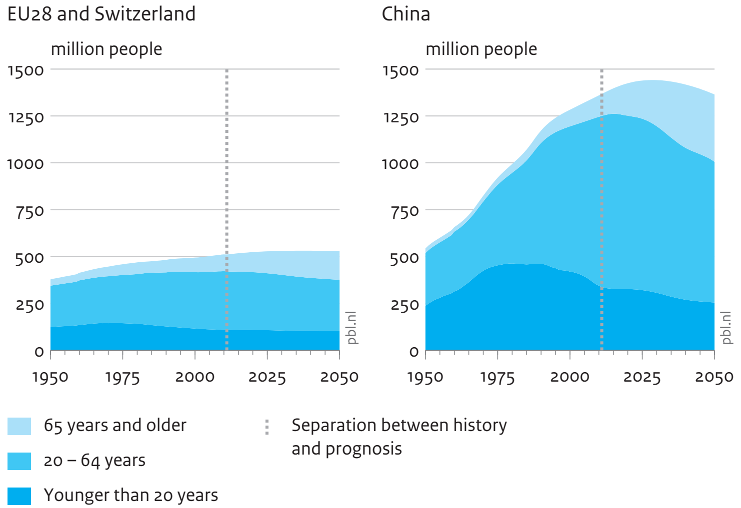
3.2 The Yangtze River Economic Belt in China and the 'Blue Banana' in Europe

Both in China and in Western Europe, national GDP per capita has increased enormously, over the past decades. However, the values are all consistently higher in Western European countries than those in China. GDP per capita varies between the 11 provinces along the Yangtze. In Shanghai, it is more than three times higher than in Yunnan (Figures 9 and 10).

Historically, the economic force of the Yangtze River lies in the east, while the urbanisation gap between the central and western regions and coastal areas has narrowed, and the urban population in the central and western regions has increased. However, the provincial differences in GDP per capita makes it difficult for the provinces to equally invest in sustainability and climate adaptation measures.

The Rhine basin largely sits in an area known as the 'Blue Banana' of Europe. The Blue Banana metaphor of economic development in Europe, developed by a group of geographers led by Roger Brunet, represents the arc running from the British Midlands to Milan, with the highest rate of economic activity in Europe (Brunet, 1989). The colloquial name 'Blue Banana' refers to the blue colour of the arc on the map they published. According to geographers, this arc dates from medieval times, and reflects ancient trade routes. It is along this belt that the industrial revolution spread around Europe, starting in the 1800s. The Blue Banana comprises a large number of large and medium-sized cities, such as Amsterdam, Frankfurt, Brussels and Zurich.

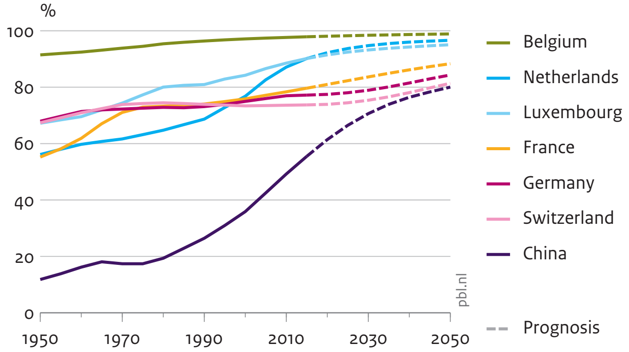
Figure 5
Population by age group



Source: OECD

The population size of the European Union is much smaller than that of China. In both regions, the population is projected to first increase, followed by a decrease in the 2030s. An ever-larger share of inhabitants will be over 65, with specific types of demand for housing, leisure and quality of the physical environment.

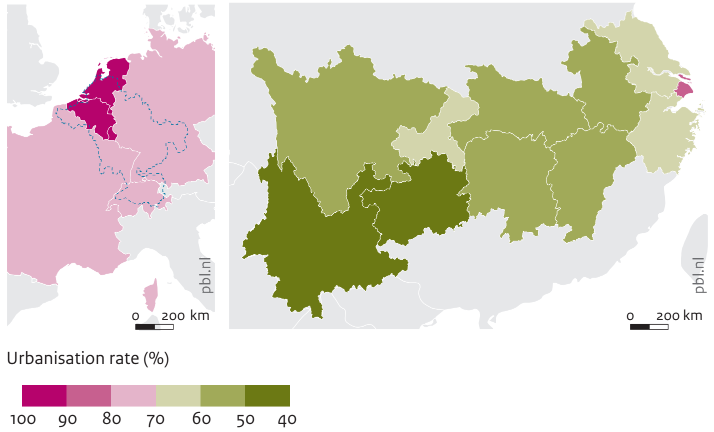
Figure 6
Urbanisation rate in China and countries along the Rhine



Source: UN 2018

The share of people living in cities is rapidly increasing in China. Many people move for their work, from the countryside to the cities. In the future, the Chinese rate of urbanisation is projected to approach that of the countries along the Rhine.

Figure 7
Urbanisation rate in countries along the Rhine and YREB provinces, 2018



Source: United Nations 2019; National Bureau of Statistics of China 2019

The share of people living in urban areas is not equally distributed over the river basins. The deltas are more urbanised than the hinterland.

Rivers also function as a guiding principle for infrastructure. Much of the infrastructure connects the cities that are located along rivers and follows the river valleys. Both river deltas have a concentration of infrastructure. Striking in the Yangtze River Economic Belt is the high-speed railway network which is extensive compared to that in the Rhine area (Figure 11).

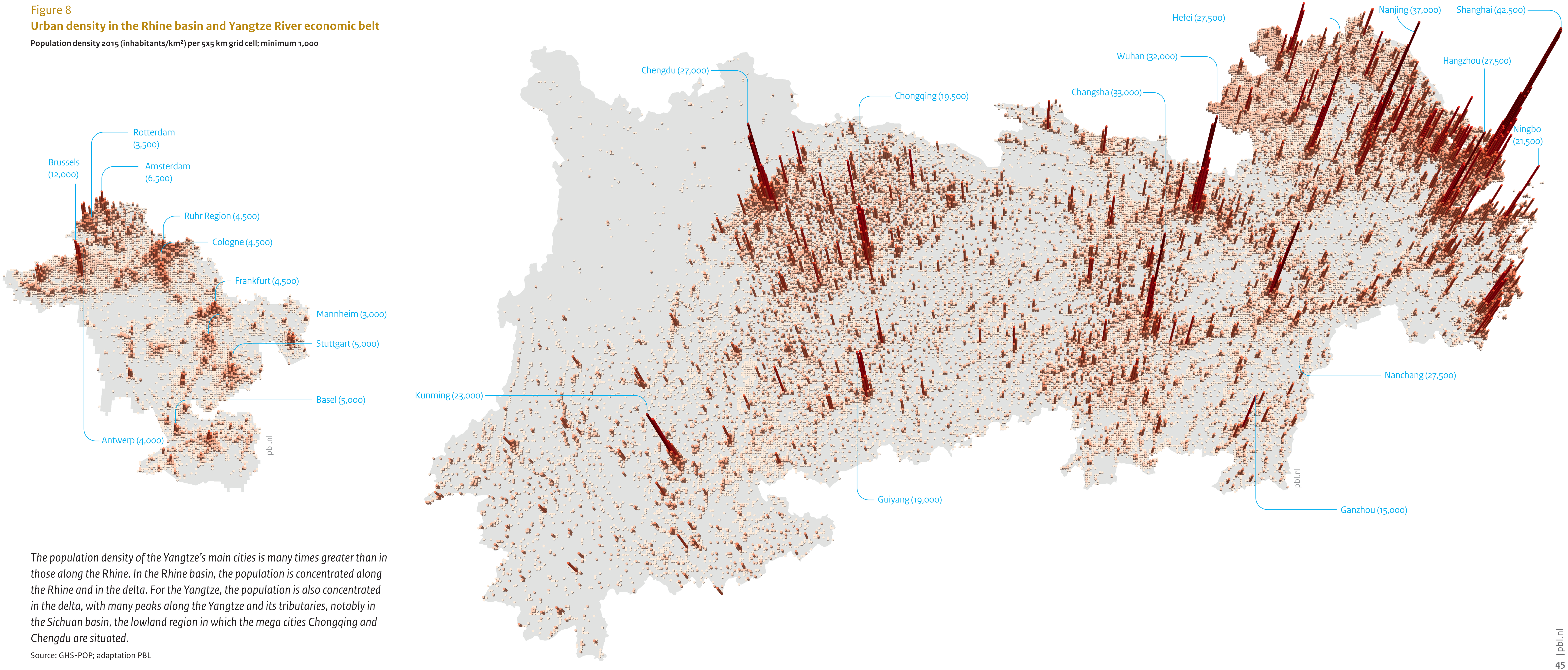
The ports are not only connected to the hinterland via road and water infrastructure, but also by pipelines. The Port ofRotterdam has a pipeline network of over 1500 kilometres to transport crude oil, oil, chemicals, and industrial gases. The pipelines run between companies within the port and to destinations, such as the Port of Antwerp, petrochemical plants, such as Chemelot (Geleen), Solvay (Wesseling), BASF (Ludwigshafen) and various airports (Figure 12). Figure 13 shows the oil pipelines from the seaports in the Yangtze Basin to the hinterland. The routing of the pipelines is independent from river courses, but in the end, the pipes connect industrial centres that usually have a relation to the river.

3.2.1 The consequences of urbanisation

There are many advantages to urbanisation: the large concentrations of people, ideas and facilities within cities foster innovation and provide easier access to development activities. Mixed-use zoning, transit-oriented development and greater building density can reduce the use of energy and resources and, through increased physical activity may, improve health. In addition, compact development of urban spaces and intelligent densification can preserve land for agriculture and

Figure 8
Urban density in the Rhine basin and Yangtze River economic belt

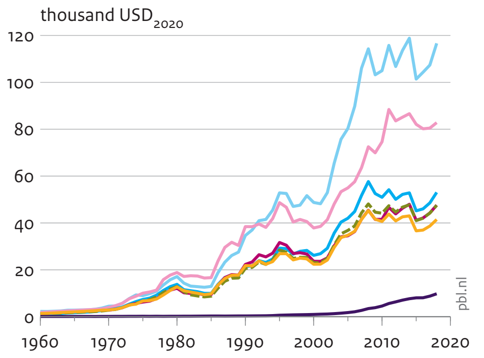
Population density 2015 (inhabitants/km²) per 5x5 km grid cell; minimum 1,000



The population density of the Yangtze's main cities is many times greater than in those along the Rhine. In the Rhine basin, the population is concentrated along the Rhine and in the delta. For the Yangtze, the population is also concentrated in the delta, with many peaks along the Yangtze and its tributaries, notably in the Sichuan basin, the lowland region in which the mega cities Chongqing and Chengdu are situated.

Source: GHS-POP; adaptation PBL

Figure 9
GDP per capita in China and countries along the Rhine



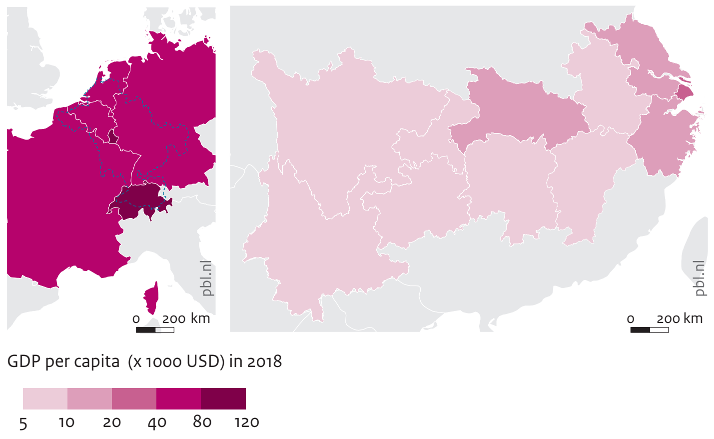
Source: World Bank 2019

In China, the Gross Domestic Product (GDP) per capita is increasing but at a much lower level than in the countries along the Rhine. Note these are national averages.

nature (IPCC 2014). On the other hand, the opportunities for renewable energy generation, such as wind and solar power, are more limited in cities compared to the rural, more sparsely built-up areas, where there is more space for wind turbines and solar panels.

It is almost impossible and extremely expensive to change a city's layout, in cases of fragmented land ownership, long periods of real estate and infrastructural depreciation and the presence of cables and pipes under road surfaces, amongst other things. Changes, if appropriate, can only take place incrementally. Once built, the urban fabric creates the preconditions for transportation and, thus, for the energy consumption of private passenger transport, for centuries to come. This is illustrated by Newman and Kenworthy (Figure 14), whose work on density posits that there is a significant and direct correlation between urban density and per-capita

Figure 10
GDP per capita in countries along the Rhine and YREB provinces, 2018



Source: United Nations 2019; National Bureau of Statistics of China 2019

Gross Domestic Product (GDP) in the Yangtze provinces is much lower than in the Rhine countries. Within the Yangtze basin, the Hubei province and the delta provinces, notably Shanghai, have higher GDPs per capita than the other provinces.

automobile usage. High population density creates favourable conditions for nearby facilities and public transport and shortens distances that not necessarily have to be travelled by car. In their graph, cities with a low population density (mostly in North America) have the highest private transport energy use per capita, while in cities with a high population density (mostly in Asia) this is much lower. European cities have a medium-sized population density and their automobile energy use is in between that of the US and Asian cities (Newman and Kenworthy, 1990).

Another consequence of urbanisation is the reduction in agriculture and nature areas, as shown in Figure 15. In China, more than 2,800 km2 of wetland were urbanised between 1990 and 2010 (CCICED, 2021). In addition, tributaries were also filled or covered, harming the river system's capillaries and their riparian retention capacity and wetland ecology.

However, the impact of urbanisation on biodiversity is greater than the effect on the built-up area alone. Intersections with infrastructure and fragmentation of habitats affect a far greater area than the city itself.

A further consequence of urbanisation is the phenomena of surface sealing: '...the destruction or covering of soils by buildings, constructions and layers of completely or partially impermeable artificial material (e.g. asphalt, concrete)' (Siebielec et al., 2013). Surface sealing harms the environment on several levels, as it affects soil biodiversity and increases the risk of flooding and landslides, as less water can be absorbed by the soil and thus flows to lower lying areas.

Urbanisation, generally, requires concrete which is made with sand. However, not all types of sand can be used for making concrete. Desert sand is less suitable due to its particle size and lack of angularity. Marine sand is also less suitable, because of its higher salinity, which accelerates concrete degradation. Therefore, the sand used in the construction sector is largely derived from pits and riverbeds. Sand mining affects sediment balance, water quality and quantity, as well as biodiversity. In addition, sand mining creates flood risks in coastal areas, as it reduces the amount of sediment that reaches the coast, in turn creating erosion. Sand mining is responsible for the reduction in sediment flux from China's major rivers (Chu et al., 2009), and also leads to environmental damage, such as a reduction in macroinvertebrate diversity in Dongting Lake (Meng et al., 2021), and it adds to the demise of unique species, such as the Yangtze river dolphin and finless porpoise (Chen, 2017).

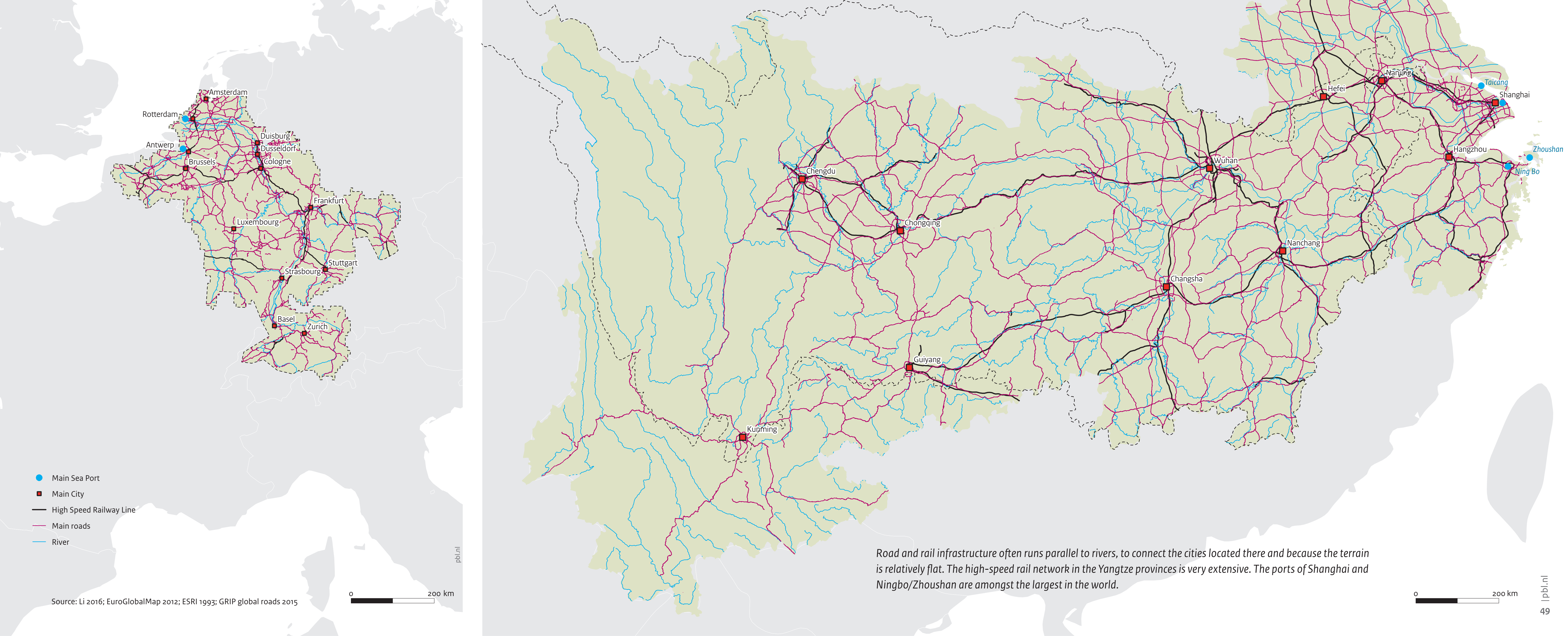
3.2.2 Urbanisation policies and design options to guide urbanisation

After the Second World War, urbanisation policies along the Rhine stimulated suburbanisation and the constructions of satellite towns. Thanks to passenger vehicles and public transport, people no longer needed to live close to their workplace. After heavy industry disappeared from the cities, these sites (and often also the buildings) were generally repurposed for housing, from the 1990s onwards. Urban expansion sites were permitted to a limited extent. China's city expansions have a relatively high population density, compared to those in Europe.

National and sub-national government authorities attempt to mitigate the negative effects of diffuse urban expansion by implementing urban containment policies, such as urban growth boundaries and greenbelts (OECD, 2018). Both can be seen along the Rhine and the Yangtze. As a result of the environmental damage caused by urban expansion and China's rapid growth rate, the government approved the containment policy of 'ecological red lines' in 2018. No new construction is allowed outside the contours of these urban growth areas, which stimulates urban densification.

Design matters when building sustainable cities — in their layout and shape and in the types of buildings. Cities do not necessarily expand concentrically: A cluster of cities can form an urban agglomeration without having a dominant, central city. Linear cities can organise efficient public transport while maintaining proximity to the green surroundings. In both Europe and China, satellite cities have been developed to reduce the pressure caused by metropolitan growth. In China, these new towns often are national flagship projects to achieve sustainability goals. They are intended to prevent over-densification in cities such as Beijing and provide for a distribution of people, work locations and, thus, urbanisation over the country.

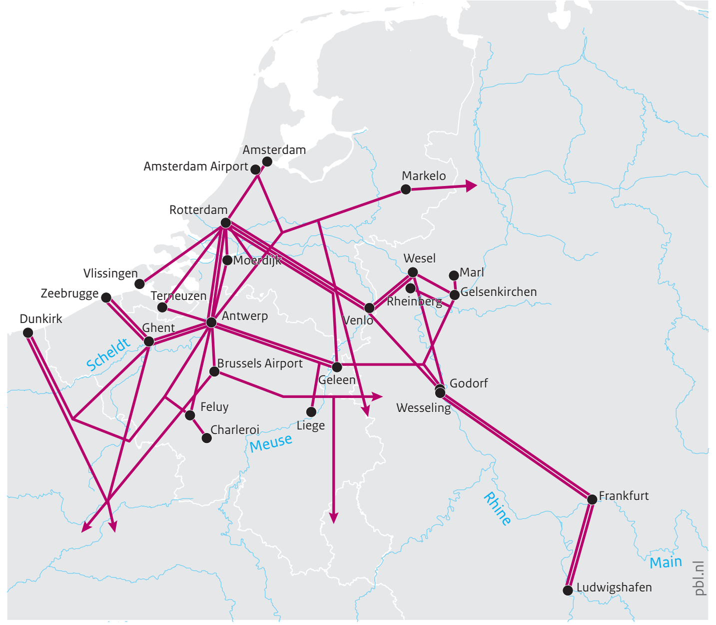
Figure 11
Transport Infrastructure in the Rhine river basin and Yangtze River Economic Belt



Source: Li 2016; EuroGlobalMap 2012; ESRI 1993; GRIP global roads 2015

Road and rail infrastructure often runs parallel to rivers, to connect the cities located there and because the terrain is relatively flat. The high-speed rail network in the Yangtze provinces is very extensive. The ports of Shanghai and Ningbo/Zhoushan are amongst the largest in the world.

Figure 12
Network of pipelines from the Port of Rotterdam

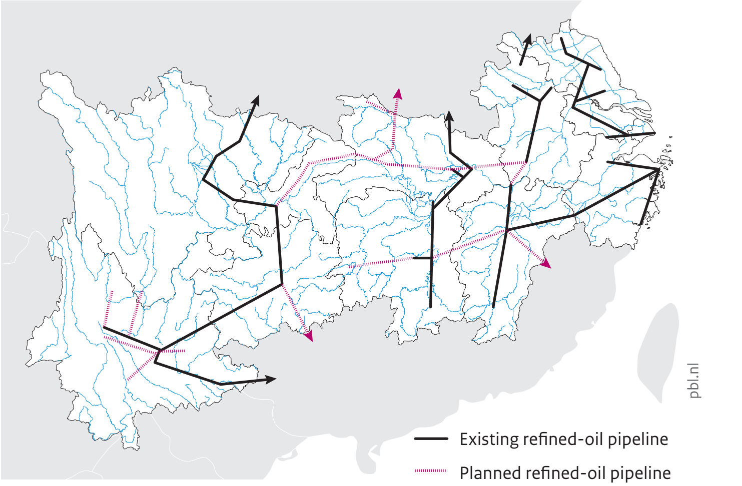


Source: Port of Rotterdam; adaptation by PBL

The pipeline network connects the Port of Rotterdam to other ports, airports and petrochemical complexes beyond the Dutch borders (in 2019).

As China has become increasingly urban, inequality between urban and rural areas increases, because urban centres tend to be where capital is concentrated. That is why China has launched its Rural Revitalization Strategy, which includes policy measures, such as modernising and transforming agriculture, food security, environmental protection, urban-rural linkages, improving rural governance and rural tourism. ICT and high-speed rail infrastructure enable people to live in the countryside and work in cities.

Figure 13
National refined-oil network in the Yangtze River Economic Belt

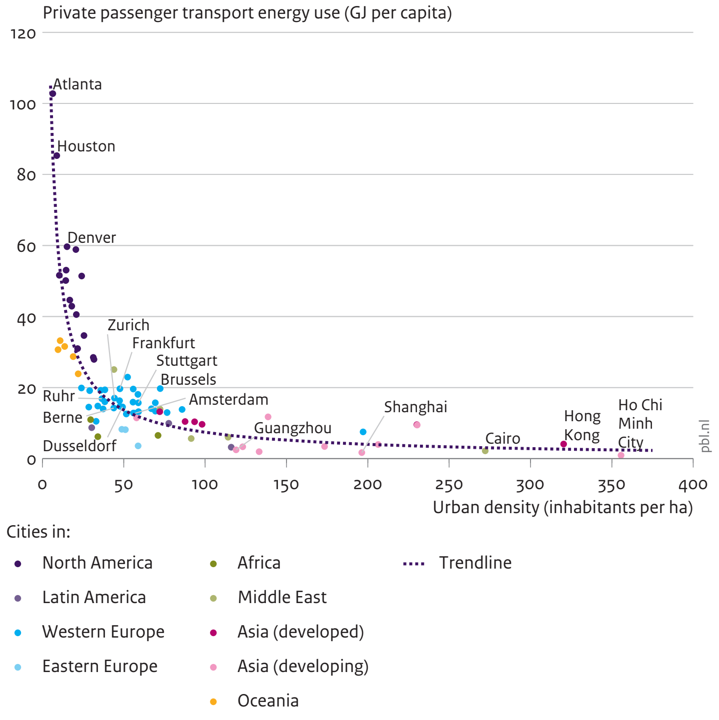


Source: NDRC 2017; adaptation by PBL

The refined-oil pipeline network in the Yangtze River Economic Belt connects cities and extends over thousands of kilometres (in 2017).

The transition from an industrial to a service-oriented economy is accompanied by less demand for space, which will also be less location-specific. ICT facilities will make it possible to work remotely and proximity will become less important. This will reduce the pressure on the city. On the other hand, urbanisation is a phenomenon that, for centuries, has seen steady progress and the transition from a fossil economy towards a circular economy benefits from closed cycles and proximity (Rood and Hanemaaijer, 2017), which means that the latter will become more important, thus increasing the pressure on the city again.

Figure 14
Private passenger transport energy use and urban population density, 1995



Source: Newman and Kenworthy 1995; adaptation by PBL

The more densely populated the city, the lower the average per-capita energy consumption for private passenger transport (mainly passenger cars). Asian cities have a high average population density and relatively low car use. In contrast, some cities in North America are sparsely populated and have relatively high car use. These ratios in the cities in the Rhine catchment are somewhere in-between the two.

3.3 Case: Chengdu's rapid urbanisation

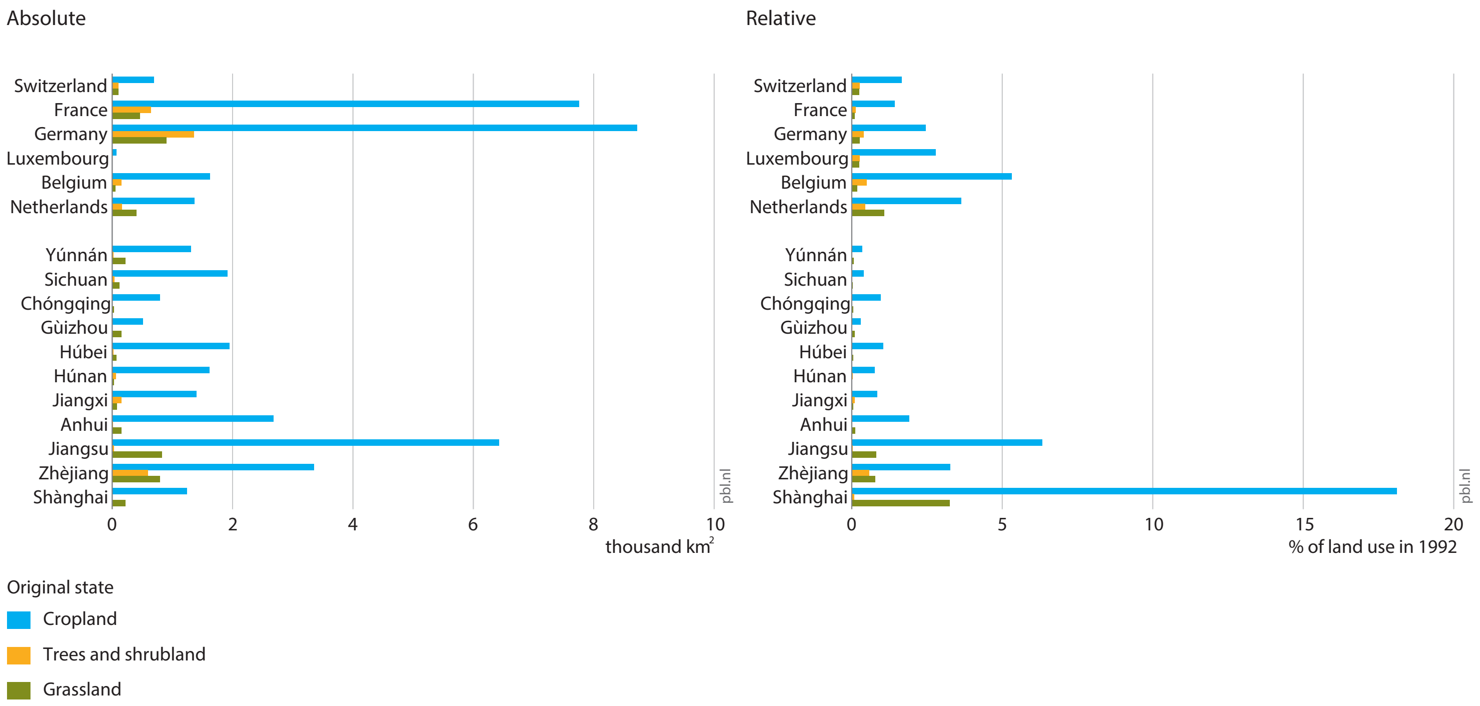
Chengdu is a good example of rapid urban expansion and development along the Yangtze. After the reform and liberalisation in China, the downtown area of Chengdu has expanded rapidly, and so has the city a whole.

The built-up area of central Chengdu was about 60 km2 in 1980 and evolved to 290 km2 in 2005, ranking 8th in China. The population of the central urban area of Chengdu was 1.6 million in 1990 and grew to over 10.2 million in 2018, making Chengdu a veritable mega-city.

There are three major drivers that facilitate the urbanisation development of Chengdu. The first driver is the high degree of centrality of Chengdu, the capital of Sichuan, and the fact that it has become the destination of the urbanising population of the province and even of the western region (especially the provinces Tibet, Guizhou and Yunnan). The second driver is the continued expansion of the jurisdiction of Chengdu, backed by the national administration, and the ongoing increase in the number of towns. The third is formed by the construction of new towns and new areas promoting the expansion of the urban scale along public transport networks. Amongst them, the Tianfu National New Area and the Second International Airport and the related future new town (currently under construction) are the core.

The construction of Tianfu New Area, south of Chengdu (see Figure 16) began in 2011. In 2019, the Tianfu New Area included a total of 31 towns and subdistrict offices in 8 districts (counties and cities), with a total planning area of 1578 square kilometres and a population of about 2 million.

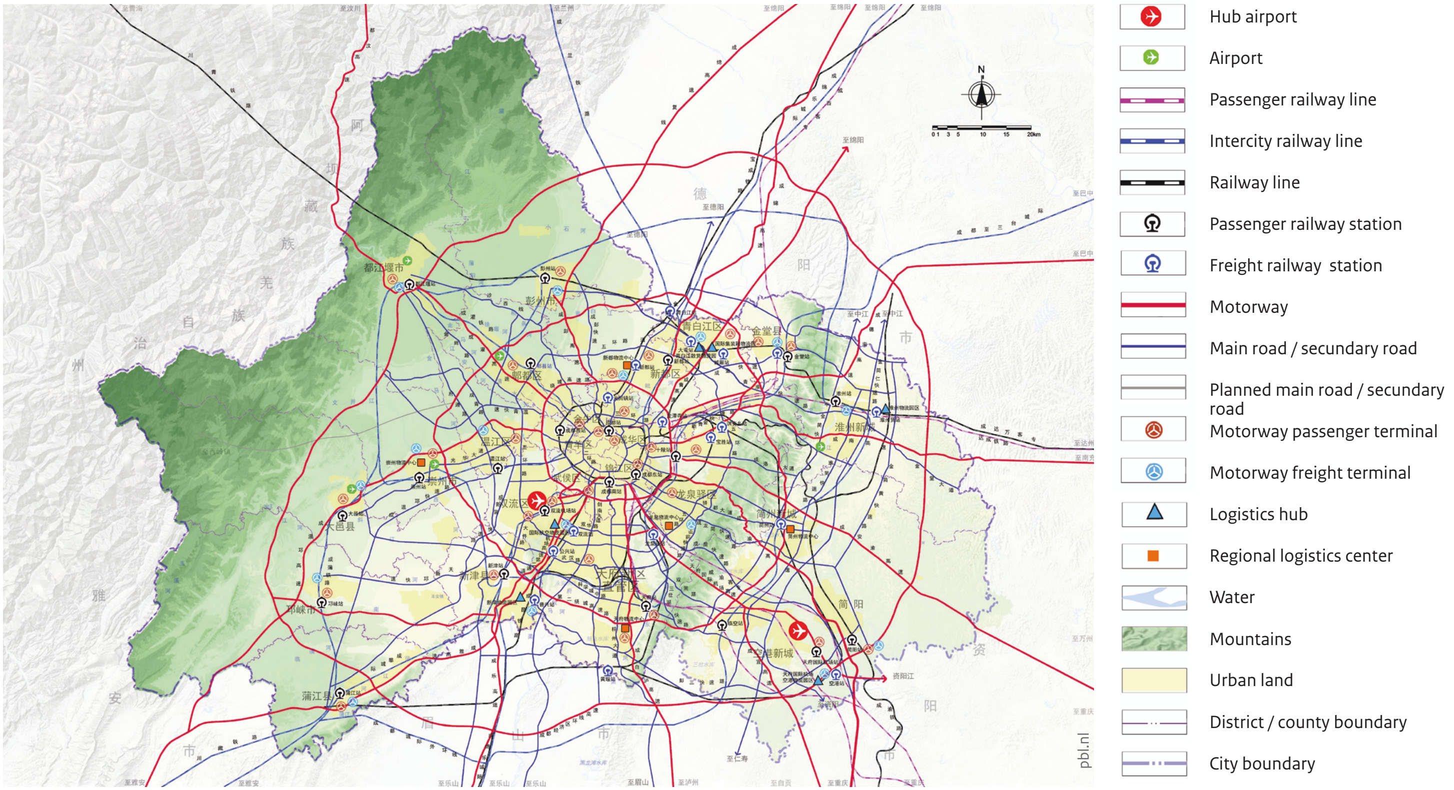
Figure 15
Land cover changes from vegetation to urbanisation, 1992–2015



Source: ESA Land Cover

Along both the Rhine and the Yangtze, urbanisation usually takes place on cropland and to a lesser extent on grassland, forested land and shrubland. In the countries along both the Rhine and in the much larger Yangtze River Economic Belt, satellite images show that approximately 25,000 km2 of urban area was added between 1992 and 2015. In relative terms, this concerns 2.4% in the Rhine countries and only 1.3% in the Yangtze River Economic Belt.

Figure 16
Chengdu City Master Plan, 2016–2035

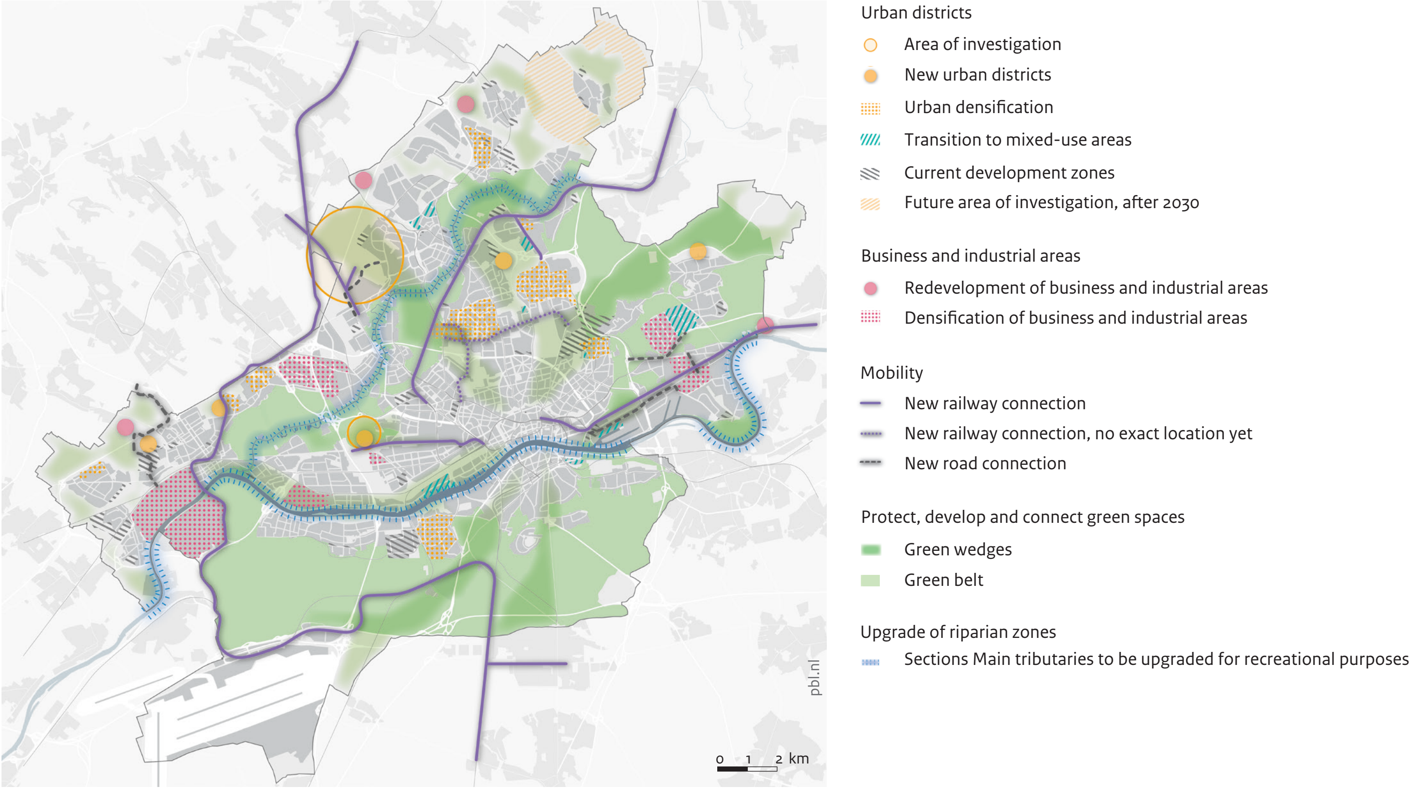


Source: Chengdu Comprehensive Plan 2016

Chengdu's master plan for 2035, including Tianfu New Area in the south and the new airport in the south-east.

Figure 17

Strategic map for the city of Frankfurt for 2030



Source: Stadtplanungsamt Frankfurt

The strategic plan for Frankfurt, indicating which districts will be transformed and densified, including new green connections.

The Chengdu Tianfu International Airport opened in 2011 and is located near Jianyang City, to the south-east of Chengdu. The first phase of the airport project is designed to meet the target of 40 million passengers, 700,000 tonnes of cargo and 320,000 take-offs and landings by 2025.

3.4 Case: Where to accommodate Frankfurt's growth?

The case of Frankfurt illustrates how Western European cities try to densify their urban fabric and to simultaneously add green areas for recreation, biodiversity and water retention.

The German city of Frankfurt is situated on the river Main, which is one of the Rhine's tributaries. The city is significant in the financial services sector, as it holds the headquarters of both the European Central Bank and the German central bank. In addition, the area hosts a large cluster of chemical industries, many trade fairs and one of Europe's busiest airports. The city has two main challenges for the decades to come: it strives for 100% renewable energy use by 2050 and aims to meet the huge demand for new dwellings. In addition to Frankfurt's 745,000 inhabitants, an additional 75,000 are expected by 2030. To catch up with the current demand, 90,000 new dwellings are needed. In contrast, the need for more industrial and business parks can be realised in the existing locations.

In terms of spatial planning, seven districts with housing stock mostly from the 1930s and 1950s are expected to be densified with a mixed-use programme and to have their green areas intensified and better connected, as an adaptation to climate change, and for recreation and biodiversity (see Figure 17). For instance, the City Forest, part of Frankfurt's green belt, boasts 3800 hectares within the city limits. The city also connects 550 km of regional park trails and has a 68 km Green Belt trail. Furthermore, it aspires to make way for green areas and green technology, while also greening rooftops, courtyards and building facades. For instance, Gateway Gardens, a new 'global business district', sits right next to a nature reserve and aspires to becoming the first 'electronic mobility city' with charging stations for electric vehicles and cycle path access to the Rhine-Main areas. This programme can accommodate 78,000 of the required 90,000 new dwellings.

Since the possibilities for densification are finite, the remaining 12,000 dwellings may be built at a greenfield location of 190 hectares, which has a good public transport connection. Another option that has been initiated by the regional government is to intensify the smaller cities around Frankfurt that can be reached within 30 minutes by train (see Figure 18). All the options are part of a broad local public debate.

3.5 Findings on the role of urbanisation in river basins

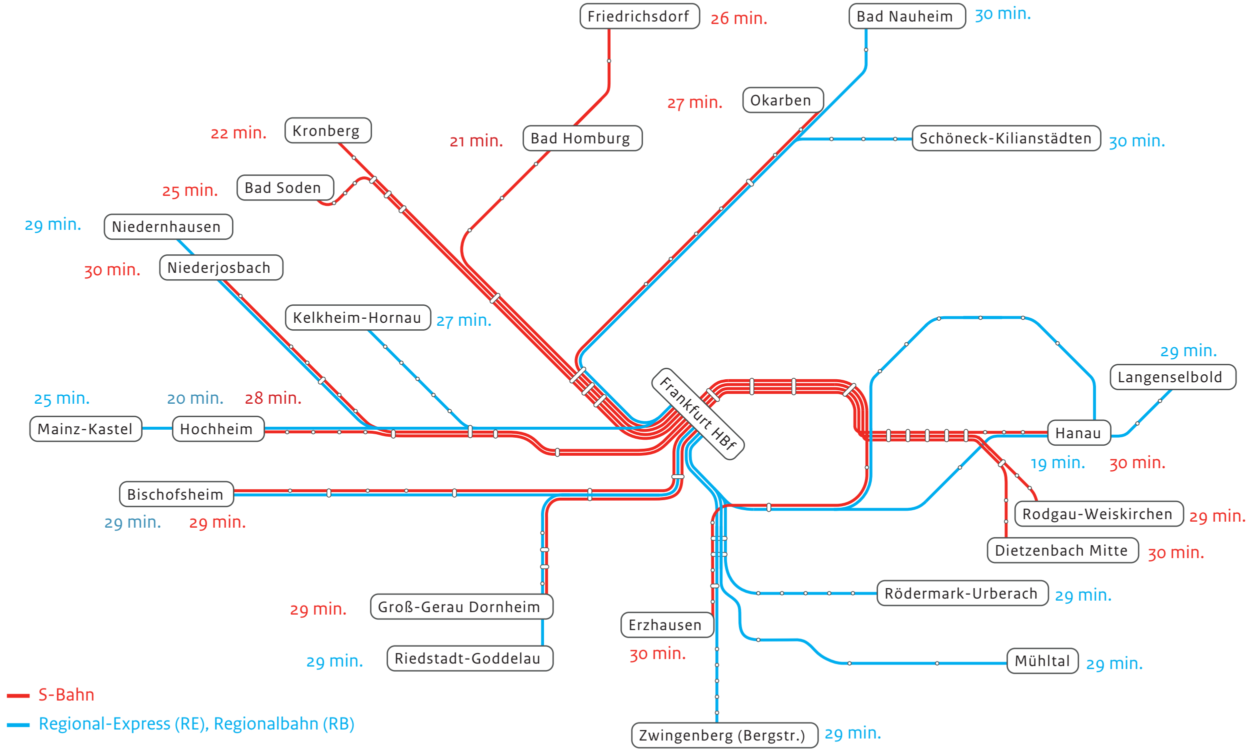
Urbanisation often takes place along rivers. Industrialisation in the Rhine Basin continued after World War II and, since the 1980s, the service sector has been strongly emerging.

Thanks to cheap labour, the Yangtze Basin saw rapid industrialisation, at the end of the 20th century, after which the transition started towards a service economy. The industrial and service sectors provide a large amount of employment, leading to a rural-urban migration and increase in income levels. In de 2020s, the population is still increasing as well as ageing. All these developments lead to an urban growth and changing residential needs, such as in terms of housing, recreation, mobility and food products, among others.

The cases in Chengdu and Frankfurt represent the 21st century urbanisation policies along the Yangtze and the Rhine, respectively. Chengdu's population has seen a six-fold increase

Figure 18

Regional railway map, indicating the cities and villages within half an hour from Frankfurt



Source: Grosser Frankfurter Bogen

Frankfurt's regional rail network within half an hour's commute from Frankfurt's main railway station. The stops along these routes offer a possible alternative to the densification of the city of Frankfurt itself.

in 30 years, and its built-up area has expanded accordingly. Frankfurt's urban expansion rate has nearly halted, showing only moderate growth compared to Chengdu. Frankfurt tries to accommodate most of its growing population within the boundaries of the city, while trying to improve the city's green structures for recreation, climate adaptation and biodiversity.

The shape and location of urban areas largely determine the quality of life and sustainability of a city and, once built, are not easy to change. Urbanisation can displace people and cut across natural habitats, especially along riverbanks, which play an important role in biodiversity. The following chapter takes a more in-depth look at these environmental issues in the river basins.

Biodiversity loss and environmental pollution in the Yangtze and Rhine basins

4

长江与莱茵河流域生物多样性的减少与环境污染

In both river basins, the biodiversity and the environment are under pressure. This chapter describes and outlines the most significant polluters and the state of the biodiversity and their development over time. Furthermore, it provides an indication of the influence of the river basin system on the location and impact of pollution. Furthermore, the fresh water supply is under pressure, on a local level, with an impact on biodiversity, agriculture, and household water supply.

4.1 Causes of biodiversity loss

In both the Yangtze and the Rhine river basins, ecosystems are under pressure. Native species are diminishing, in water bodies as well as on land. This biodiversity loss has many causes. Some of the most important causes of biodiversity loss have an economic background related to the agricultural, forestry and fishery sectors (Karlsson-Vinkhuyzen et al., 2018). Agricultural expansion takes about one third of the global terrestrial land surface, in addition to rapidly expanding urbanisation and infrastructure building. These changes have mostly come at the expense of forests, wetlands, and grasslands (IPBES, 2019). Furthermore, changing temperatures and water levels have also affected biodiversity and ecosystems (IPBES, 2019). The paving of riverbanks has destroyed natural river banks with their specific flora and fauna that have both water and land as habitat.

An indicator of biodiversity loss is the Mean Species Abundance (MSA), the mean abundance of original species relative to their abundance in undisturbed ecosystems (Alkemade et al., 2009). In 2015, large parts of the Rhine and Yangtze catchment areas had a terrestrial MSA of between 20% and 40%, meaning that 20% to 40% of the original biodiversity on land was still present. In water bodies, along large parts of both Yangtze and Rhine catchment areas, values are even below 20%. Only a few areas have a terrestrial or aquatic MSA of over 80% (Figure 19).

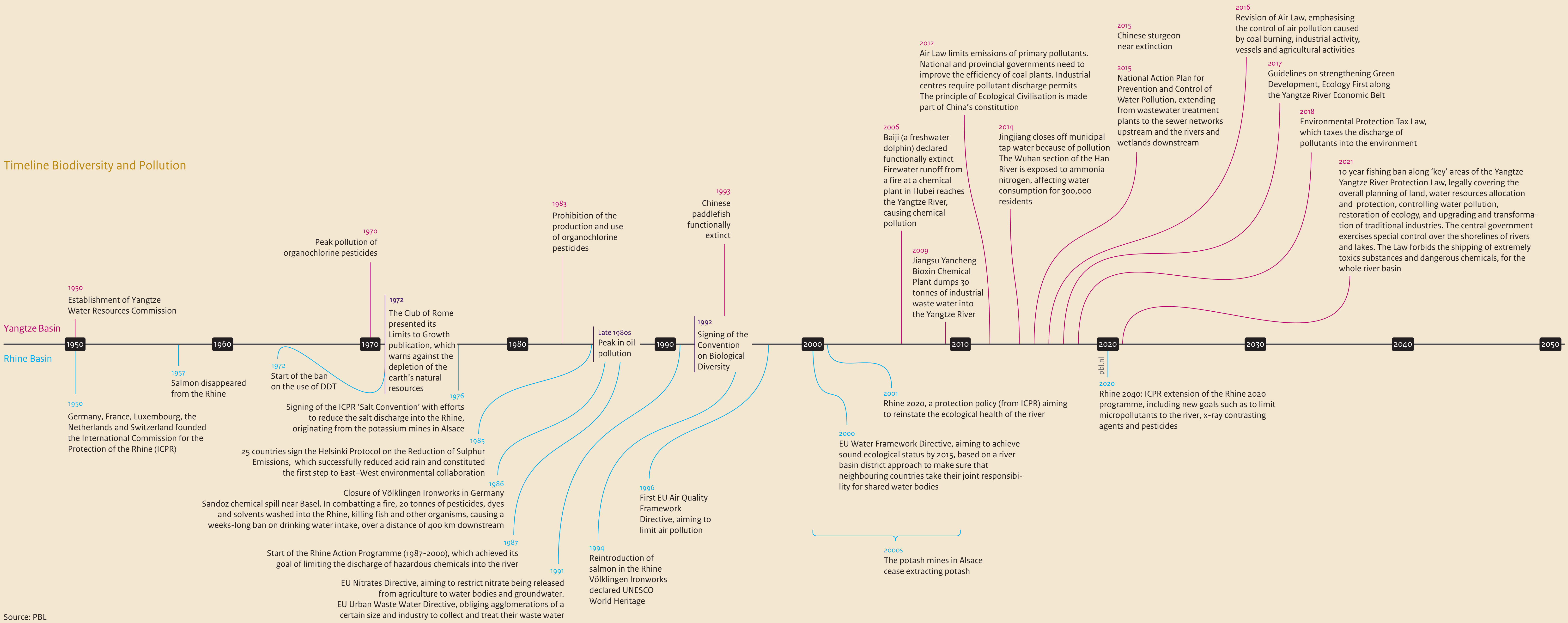
Below, several causes of biodiversity loss are discussed, specifically for the Yangtze and Rhine basins.

4.1.1 Invasive species crowding out native species

Invasive species may crowd out native species. These invasive species are typically introduced through commercial and tourist activities, including in ballast water, fish bait buckets, boats and trailer hulls and shipments of fish (Lodge et al., 1998).

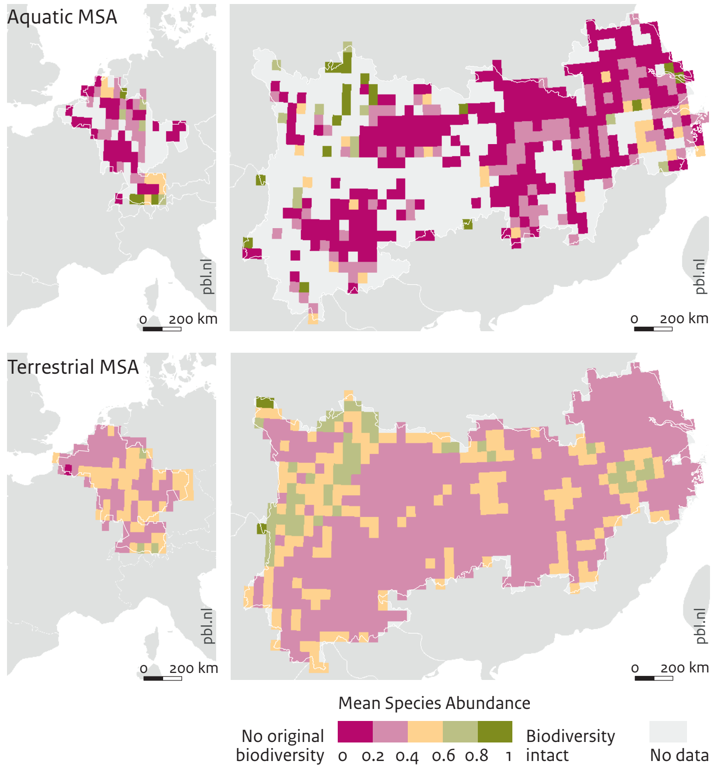
The major seaports at the mouth of the river are, in part, one of the reasons why the prevalence of foreign species has unintentionally further exacerbated in the Rhine and especially the Upper-Rhine (Leuven et al., 2009). Furthermore, the network of canals in the Rhine River Basin has increased the level of invasive species. The opening of the Rhine-Danube Canal in 1992, connecting two river basins, has become the most important route for invasive species. Due to these gateways, the numbers of non-indigenous macroinvertebrates increased, between 1800 and 2005, from less than 1 to more

Timeline Biodiversity and Pollution



Source: PBL

Figure 19
Mean Species Abundance, 2015



Source: GLOBIO

Mean Species Abundance represents the remaining abundance of native species, relative to a natural state. For example, if a forest is cleared, then the MSA is based on the surviving forest species. MSA is modelled on a relative scale from 0 per cent (ecosystem destroyed) to 100 per cent (ecosystem intact). In the Yangtze and Rhine basins, both aquatic and terrestrial MSA is low.

than 13 species per decade. Invasive species tend to tolerate higher salt contents, temperatures, organic pollution and flow, more so than native species (Leuven et al., 2009).

The Yangtze River basin is connected to northern rivers via the Grand Canal, which origins date back to over 2000 years ago and has developed further, ever since. The planned construction of another North-South canal in western China is heavily discussed for its ecological risk considerations.

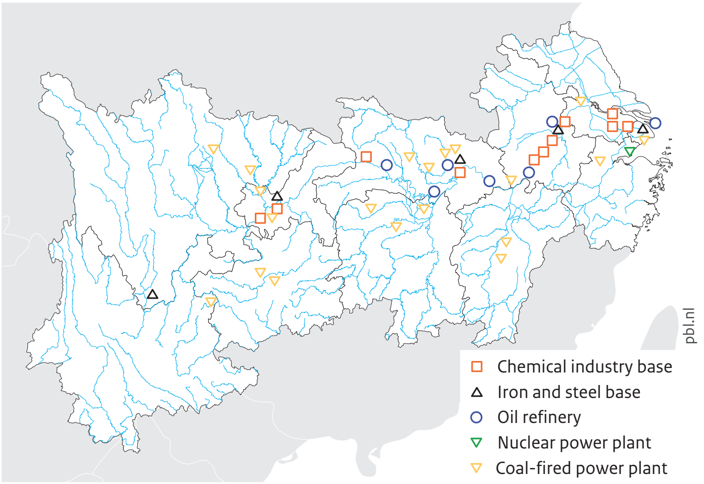
4.1.2 Industrial pollution of soil and water bodies

Industry — usually located along rivers because of the availability of fresh water and cooling water and for logistical reasons — affects the level of river basin pollution, in many ways.

For many years, severe polluting incidents, such as the Sandoz chemical spill in Switzerland in 1986, had serious consequences for downstream life in the Rhine River over hundreds of kilometres. In addition to significant polluting incidents, the presence of industrial activity, waste landfills and oil industry effect the air, water and soil quality of the surrounding areas. Across Europe, the intensive use of chemicals has resulted in many contaminated sites. Contaminated soils can affect human health in various ways including via ingestion, skin contact and dermal absorption of contaminants.

Along the Yangtze, there are five major iron and steel production sites, seven major oil refineries, as well as many petrochemical production sites (Figure 20). The contradiction between water intake and sewage discharge in upstream and downstream cities is prominent: 179 drinking water source areas and 173 industrial water use areas along the route are often arranged adjacent to each other, lacking coordination mechanisms.

Figure 20
Main industrial plants and power plants in the Yangtze River Economic Belt, 2010



Source: NDRC 2017, CAUPD

The industrial sites and power plants in the YREB are all linked to the Yangtze and its tributaries.

In 2005, 81% of China's 7555 chemical and petrochemical construction projects were at environmentally sensitive locations, such as rivers and densely populated areas, and 45% were major sources of risk (MEP 2006).

4.1.3 Polluted rainwater and wastewater from industry and households

In Europe, and particularly in Germany because of the reconstruction of its industry after the Second World War, the Rhine has experienced a drastic increase in wastewater pollution from urban and industrial sources, which has greatly reduced biodiversity and life in the river and threatened the suitability of the river as a source of drinking and agricultural water.

Although 96% of rainwater and waste water from industry and households in the Rhine River basin is treated at municipal wastewater treatment plants (ICPR, 2021), micropollutants may still affect rivers and cause problems. The pollution from waste water, in recent years, has drastically reduced in the Rhine catchment area. Nowadays, municipal waste water, including run-off, is treated at wastewater treatment plants, whereas industrial waste water is treated either at municipal wastewater treatment plants or at on-site treatment plants that discharge the treated water directly into the river.

Until 40 years ago, China's had virtually no wastewater treatment. However, economic development and drastically increasing pollution of the country's rivers, led to an increase in its wastewater treatment capacity — although the latter did not develop as rapidly as the former Pollution still threatens drinking water, mainly in the Yangtze River Delta.

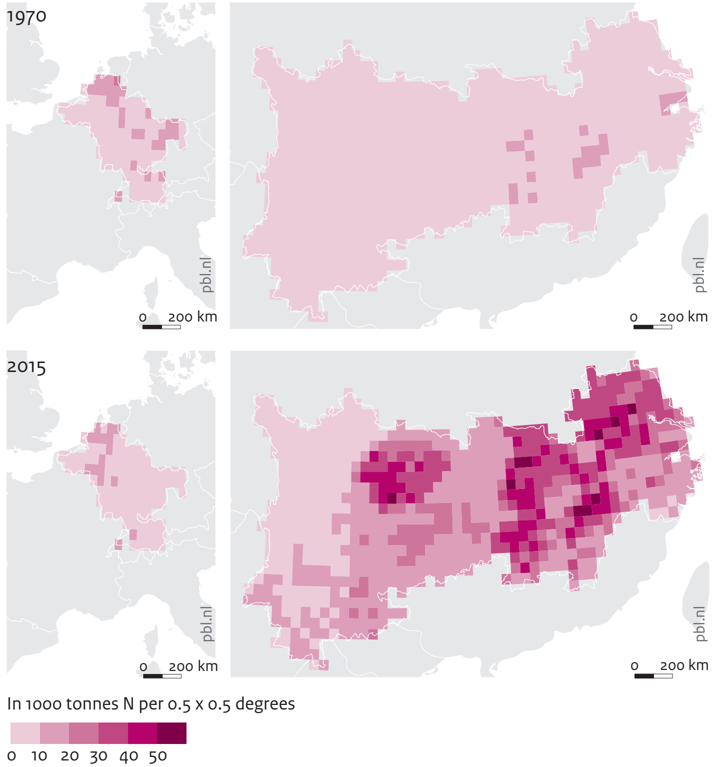
4.1.4 Nutrients from agriculture and sewage discharge

Nitrogen and Phosphorus are essential nutrients for plants. Fertilizers, primarily nitrogen and phosphorus that contributed to boosting global food production, have found their way into nearly every waterbody across the globe. This is caused by nutrient emissions in sewage water discharge and run-off from agricultural land.

Wastewater treatment plants successfully remove nutrients from urban sewage. The remaining problem, currently, is that of fertilisers and excess manure from agriculture leaching into the river. Because of its diffuse nature, this problem is difficult to mitigate and control.

Nutrient losses from agricultural land occur via gaseous emissions to air (nitrogen compounds), surface run-off and erosion (nitrogen and phosphorus compounds) and leaching from the soil to groundwater and eventually to surface

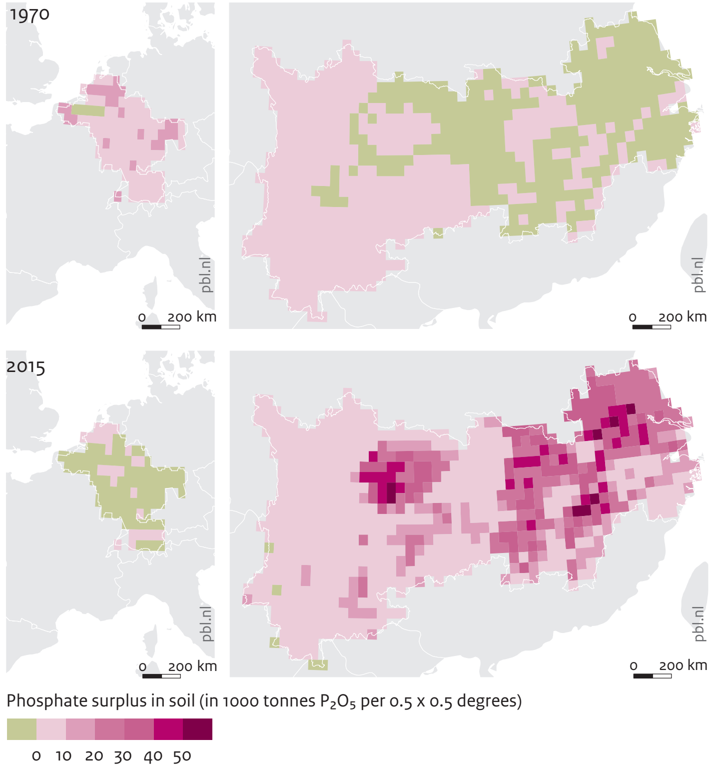
Figure 21
Nitrogen soil surplus in the Rhine river basin and YREB



Source: Bouwman et al. 2017

Nitrogen soil surplus is the input of nitrogen into the soil through the application of fertilizer and manure, minus the output as contained in animal and plant products as well as in any manure removed. Nutrient problems persist in parts of the Rhine basin, but along the Yangtze, nitrogen soil surplus increased substantially, between 1970 and 2015.

Figure 22
Phosphorus soil surplus in the Rhine river basin and YREB



Source: Bouwman et al. 2017

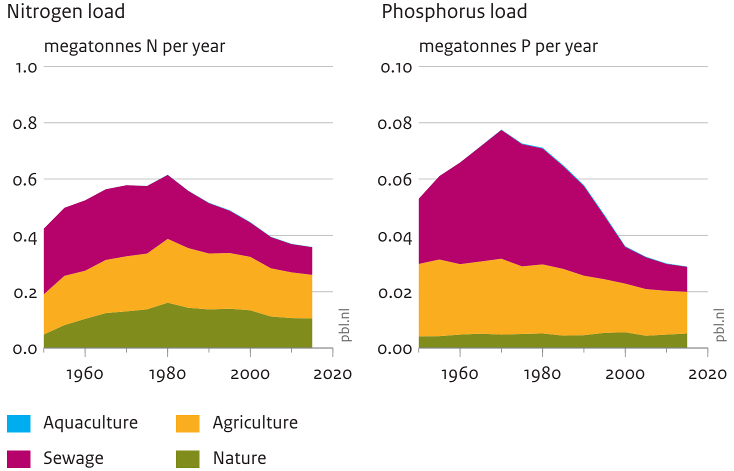
Phosphorus soil surplus is the input of phosphorus into the soil through the application of fertilizer and manure, minus the output as contained in plant products. Phosphorus is chemically bound to soil minerals and slowly becomes available as a nutrient for plants. Thus, under surplus conditions, it accumulates in the soil until the soil is saturated. Along the Yangtze, the phosphorus soil surplus increased substantially between 1970 and 2015, whereas it decreased in Rhine River basin.

waters. Nitrogen compounds that are lost through gaseous emissions impacts air quality and human health and can lead to eutrophication after redeposition. Nitrogen compounds leaching to groundwater can affect the water's suitability for drinking water production. Major threats caused by nutrient enrichment of inland and coastal waters are the creation of dead zones and harmful algal blooms.

Surplus application of nutrients on agricultural land as reflected in soil surface budgets (Figures 21 and 22) is a useful indicator of the losses to the environment. It consists of the input of nutrients into the soil from the application of fertilizer and manure, minus the output as contained in animal and plant products as well as in manure removed from agriculture. The magnitude and timing of the emissions from agricultural systems have differed between China and Western Europe. In the Rhine River basin, nitrogen and phosphorus budgets (difference between input and withdrawal via crops) started to increase rapidly after the Second World War. They began to decline in the 1970s (phosphorus) and 1980s (nitrogen). The nitrogen budgets were smaller in 2015 than in 1970, which is clearly shown in Figure 22. At present, the available soil budgets for phosphorus are even negative in many European countries, and are projected to remain this way for many years into the future (Figure 23). This is related to the past accumulation of surplus applications through chemical soil absorption, which has increased the available soil phosphorus and decreased the need for fertilizer input, while crop yields even increased. Nitrogen does not accumulate in soils to the same extent.

The Yangtze basin shows a different pattern. Rapid intensification of nutrient use in the Yangtze River basin started in the 1970s and is still continuing today. The large phosphorus surpluses that must have accumulated suggest that, similar to the Rhine River basin, phosphorus fertilizer use can be reduced, in the short term.

Figure 23
Nitrogen and phosphorus loads in the Rhine



Source: PBL

The nutrient loads that flow into the river have decreased in the Rhine, since the late 20th century. Sewage treatment, in particular, has contributed to this decrease.

In the Rhine River basin, sewage discharge was the dominant anthropogenic source of nitrogen and phosphorus, prior to the Second World War; there was a strong reduction after 1970, particularly of phosphorus (Figure 23). Natural ecosystems were the dominant source of nitrogen in the early 20th century in the Yangtze River basin, and agriculture became the dominant source after 1970. Since 1990, the contribution of sewage to the Yangtze River basin increased due to the development of megacities in the Yangtze River Delta, such as Shanghai (Figure 24).

Capturing point sources, such as effluent discharges from sewerage systems, is relatively easy. For the future, however, the widespread inflow of nutrients from agriculture remains a persistent problem in both the Yangtze and Rhine basins.

4.1.5 Air pollution, a persistent problem

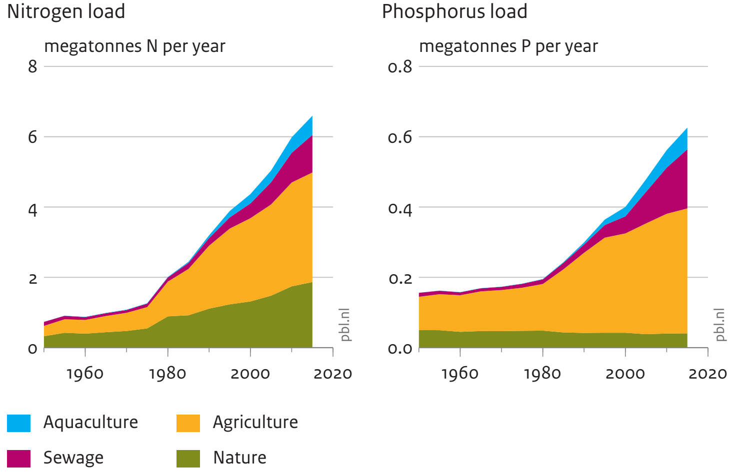
Air pollution, including particulate matter, is the harmful consequence of industrial activity, residential heating and motorised transport. Although rivers do not distribute air pollution, riverbanks are the locations of cities and industries that do. Air pollution has a large-scale impact and is a persistent problem along both the Rhine and the Yangtze, but its development over time differs greatly between the two.

After 1970, emissions of sulphur dioxide (Figure 25), which are released from fossil-fuel combustion containing sulphur (e.g. coal and oil), sharply decreased within the Rhine basin. This was due to a combination of autonomous developments in technology, public debate and internationally coordinated policies. However, the air in urban areas continues to be highly polluted. In the Yangtze River basin, we see a large increase in sulphur dioxide emissions, in urban areas as well as along the rivers. Energy saving may add to a reduction in emissions, using renewable energy sources and installing end-of-pipe filters in power plants, factories, and combustion engine vehicles, amongst other things. More fundamental reductions in air pollution could be achieved by a change from an industrial to a service economy.

Nitrogen oxide emissions from fossil-fuel combustion in industry and road traffic have decreased in the Rhine River basin since 1970, but not by as much as sulphur dioxide emissions. Emission levels are persistently high, due to the emissions from motorised traffic. In large parts of the Yangtze River basin, we see an increase of nitrogen oxide emissions (Figure 26).

Figure 24

Nitrogen and phosphorus loads in the Yangtze



Source: PBL

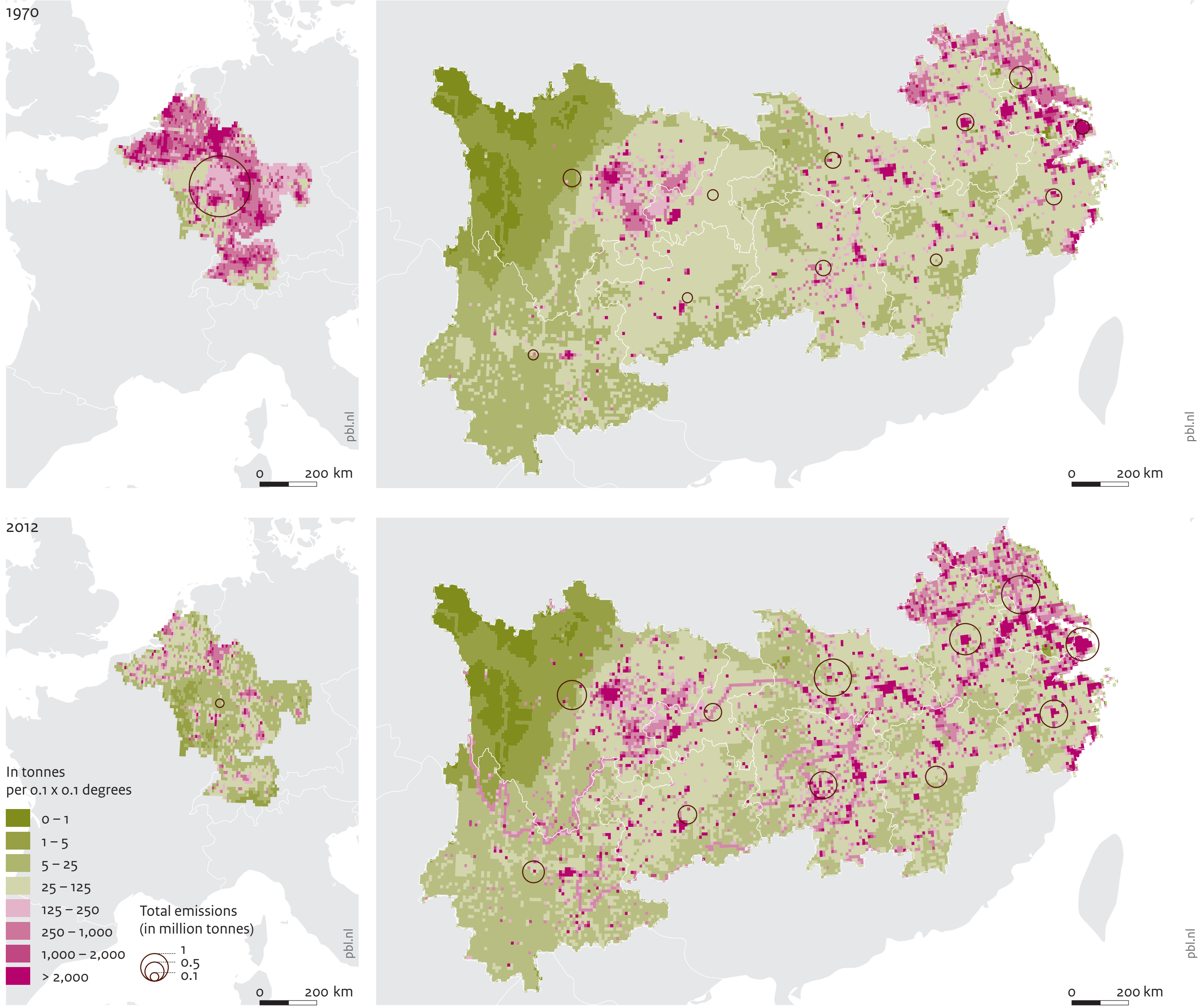
In the Yangtze, the nitrogen and phosphorous loads that flow into the river both strongly increased, since the late 20th century. Fertilizer use in agriculture, in particular, has contributed to this increase.

Particulate matter (PM) and its impact on human health tends to be concentrated in urban centres. Along the Rhine, we see a concentration of particulate matter emissions with a diameter of less than 2.5 µm (PM2.5) in urban centres and industrial clusters. In the Yangtze River basin, we see a concentration of such emissions in the lower and middle reaches of the Yangtze.

In the Rhine basin, the emission of sulphur dioxide from the combustion of sulphur-containing fossil fuels, sharply decreased, after 1970, whereas the Yangtze River Economic Belt saw large increase, particularly visible along the rivers and in the urban centres. ▶

Figure 25

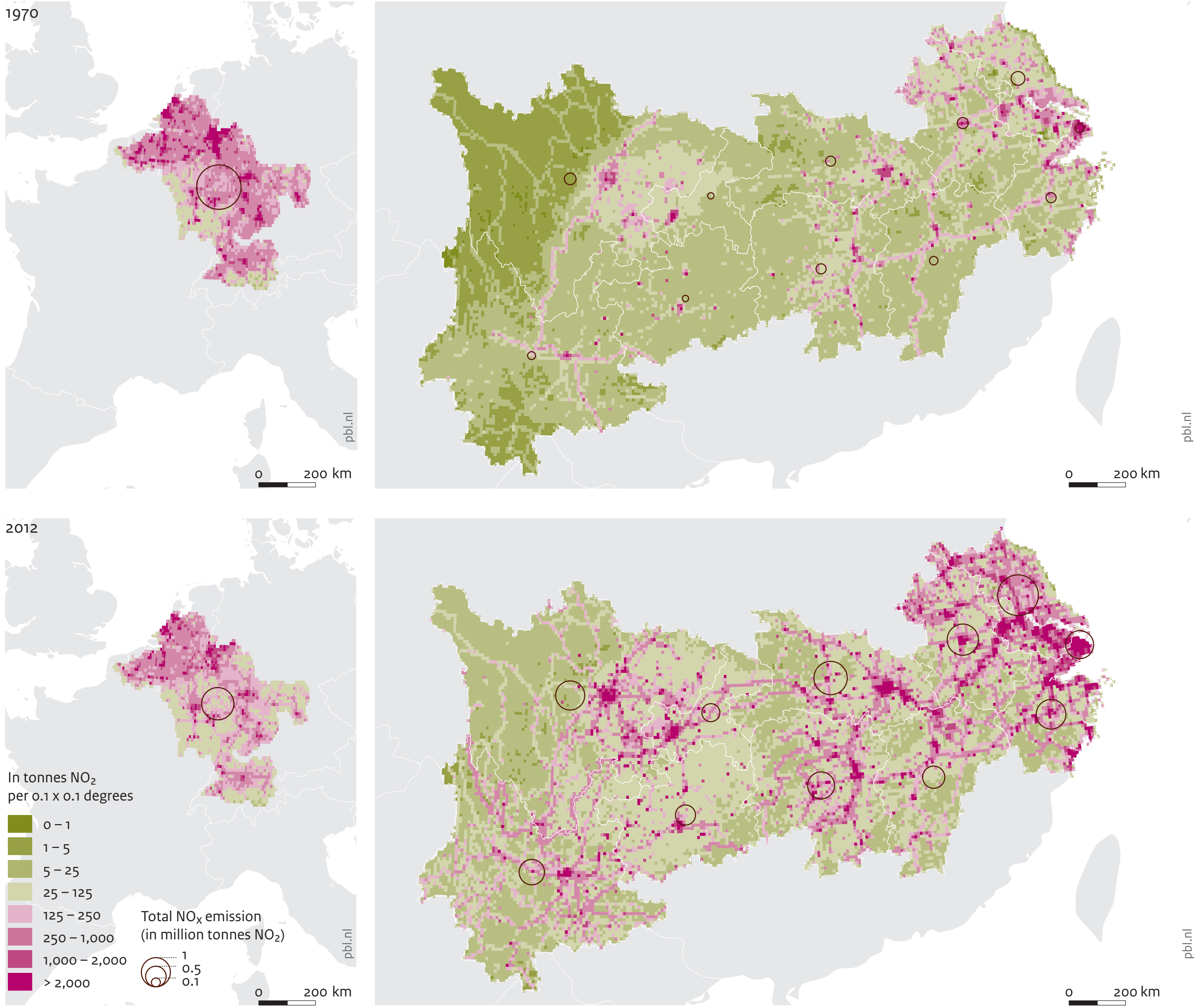
SO_2 emissions in the Rhine river basin and Yangtze River Economic Belt



Source: EDGAR v4.3.2

Figure 26

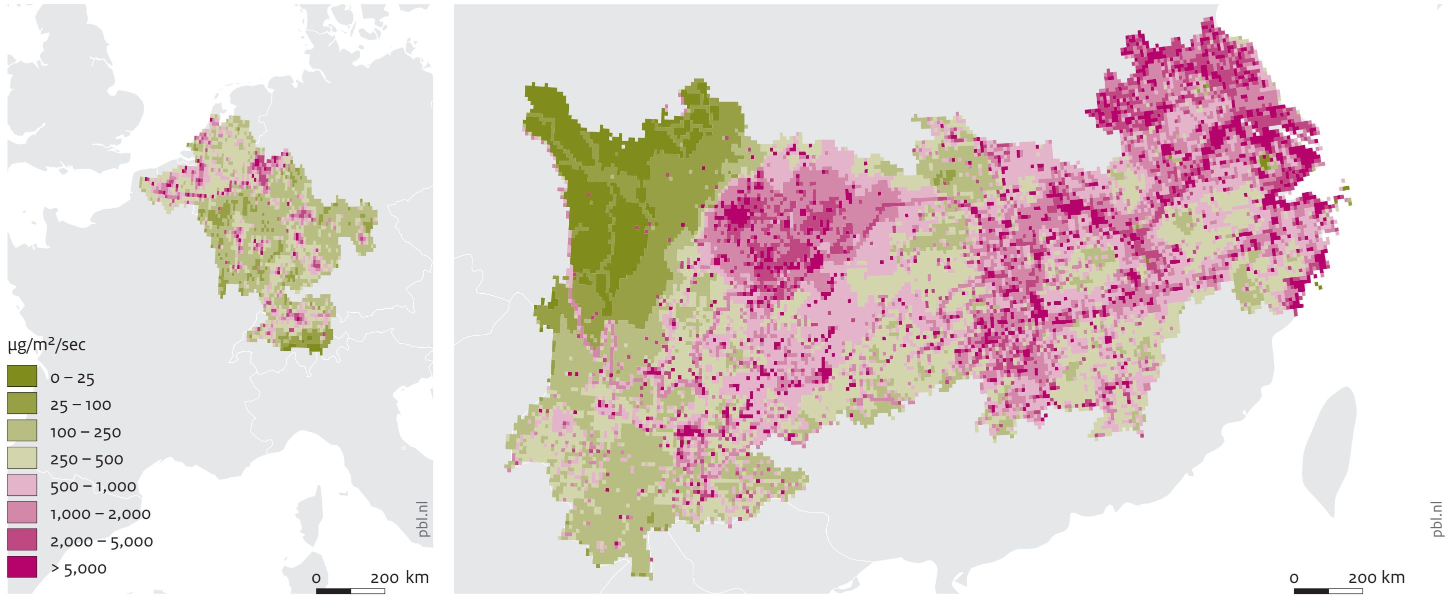
NO_x emissions in the Rhine river basin and Yangtze River Economic Belt



Source: EDGAR v4.3.2

Figure 27

Emissions of particulate matter (PM2.5) in the Rhine River basin and Yangtze River Economic Belt, 2012



Source: EDGAR v4.3.2

Airborne particulate matter, including from transport, industry and residential heating, is a problem, in the urban areas of both the Yangtze and Rhine River basins.

In the Rhine basin, the emission of nitrogen oxide from the combustion of fossil fuels in industry and transport have decreased, since 1970. Levels nevertheless continue to be large due to the emissions from road traffic. Large parts of the Yangtze River basin saw an increase in nitrogen oxide emissions in cities and along transport corridors.

Furthermore, river courses are clearly visible, which likely has its origins in shipping emissions (Figure 27). In China, particulate matter is a significant problem, especially in cities (Chan and Yao, 2008). However, between 2010 and 2019, outdoor PM2.5 levels in China decreased by 30%, in part due to the shift from coal to natural gas in industries and households (Health Effects Institute, 2020).

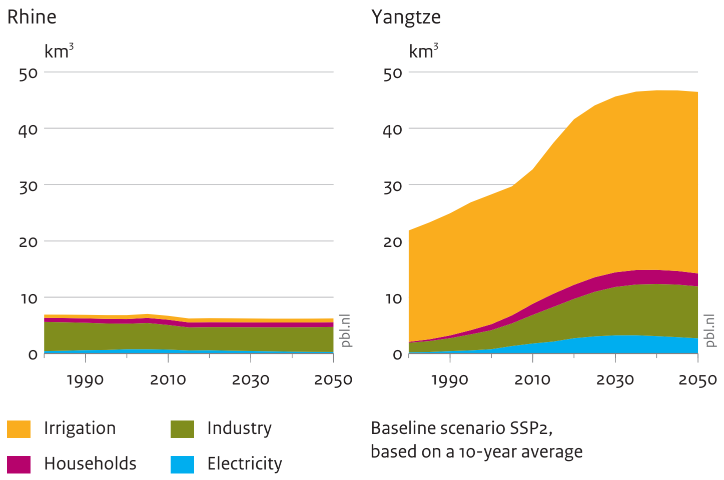
4.1.6 Increasing water scarcity

Low water levels make rivers more susceptible to pollution, have a negative impact on river ecosystems and on the strength of embankments, and may also hinder navigation.

As shown in Figure 28, in the Yangtze River basin, the greatest share of fresh water is used for irrigation. In contrast, along the Rhine, the greatest share is used for industrial purposes.

In addition to water consumption, water withdrawal (Figure 29) is also important, and includes not only water that is consumed, but also water that is withdrawn, mainly, for hydropower plants and for cooling power plants and industry, and afterwards flows

Figure 28
Water consumption



Source: PBL IMAGE

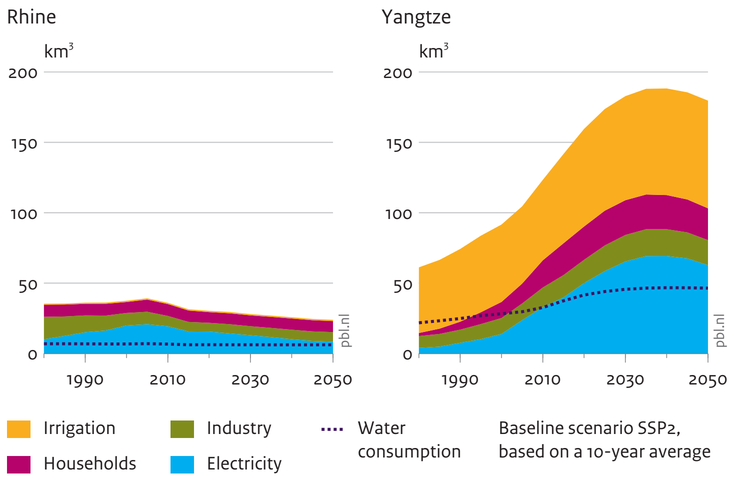
Water consumption in the Yangtze River basin is increasing and is expected to continue to do so, in the near future. The largest share of fresh water is consumed for irrigation. Along the Rhine, the largest share is consumed in the industrial sector. Note the difference in basin sizes.

back into the river. Although this water is not consumed, it is important that it is available in sufficient quantities.

Currently (2022), there are water shortages along the Yangtze River in Chengdu, Chongqing, Central Yunnan and Central Guizhou, and in the middle reaches, in Dongting Lake, during the dry season.

By 2050, water withdrawal from the Yangtze Basin is expected to have increased by more than 70%, compared to 2010, and water consumption by more than 40%. This will create pressure on the water resources because of a growth in the number

Figure 29
Water withdrawal



Source: PBL IMAGE

Water withdrawal from the Rhine is decreasing, both for consumption, cooling and hydropower plants. Withdrawal from the Yangtze will continue to increase up to 2030, after which time it will begin to decrease. Note the difference in basin sizes.

of households and in industrial and agricultural production. Groundwater abstraction can also lead to local soil subsidence. The peak in water use is expected to be around 2040, after which time it will begin to decrease. This expected decline is a result of a decrease in population and increasing efficiency.

Climate change (Vonk et al., 2015) has caused the water temperature in both the Yangtze and the Rhine to increase and this will continue in the future (Figures 30 and 31). This has consequences for aquatic life. In addition, the availability of cooling water for power plants will be hampered by smaller summer flows. Causes include increased evaporation, in combination with greater fluctuation with a larger share of rainwater and a decrease in the meltwater from glaciers. Along the Rhine, the temperature of the cooling water that is discharged may not exceed 30 °C, for reasons of water ecology. On average, the water in a power station heats up by 7 °C. Therefore, if the water temperature exceeds 23 °C, the intake of cooling water must be stopped, and the generation of power should cease — unless cooling towers are available.

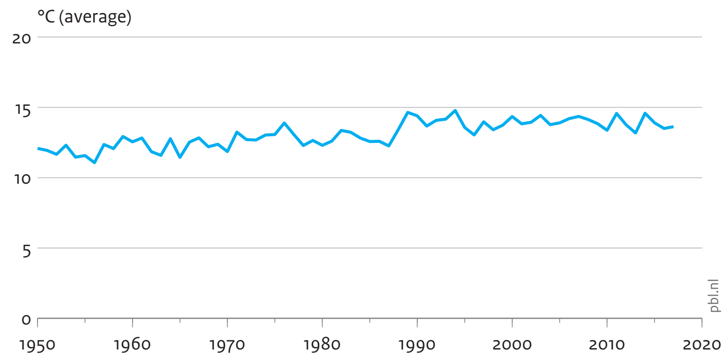
4.1.7 An increasing number of river dams obstruct natural river flow

River dams play a significant role in flood safety, clean energy production and irrigation. However, river dams lead to a decline in aquatic biodiversity and obstruct sediments from reaching downstream sections, typically weakening natural flood prevention. Without a sufficient, regular supply of sediment, erosion will dominate in the delta area — eventually leading to its disappearance. Environmental flow levels are often too small, while sudden peak flows disrupt the flow regime. Moreover, the water that is released from reservoirs is often much colder than the river, thus disrupting ecological processes (CCICED, 2021).

River dams along the Rhine are mainly located in the upper course of the river and along the smaller tributaries. Along the Yangtze, they are to be found in its lower and middle course.

Compared to the Rhine catchment, the number of dams in the Yangtze catchment, with 52,000, is very large (CCICED 2021). Moreover, a huge increase in small dams is foreseen in the Yangtze River Basin (Figure 32). The numerous cascading small dams may be more harmful for the connectivity of habitats and sediment flows within rivers than the impact of the fewer large dams (Yang et al., 2019). Reservoirs are estimated to trap between 20% and 30% of sediment fluxes, with high increases in trapping rates at the end of the 20th century (Dunn et al., 2019).

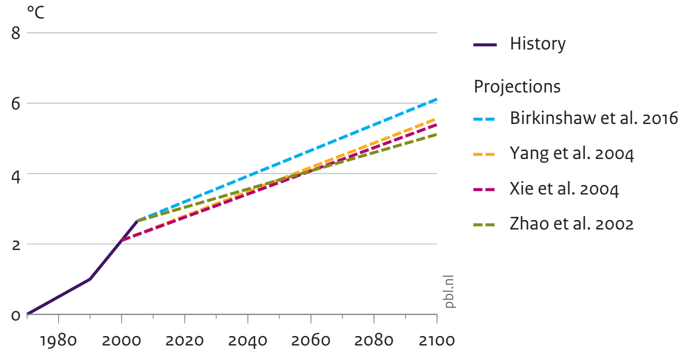
Figure 30
Water temperatures of the Rhine at Lobith



Source: Rijkswaterstaat; adaptation by PBL

The average water temperature in the Rhine has increased and will continue to do so, due to climate change.

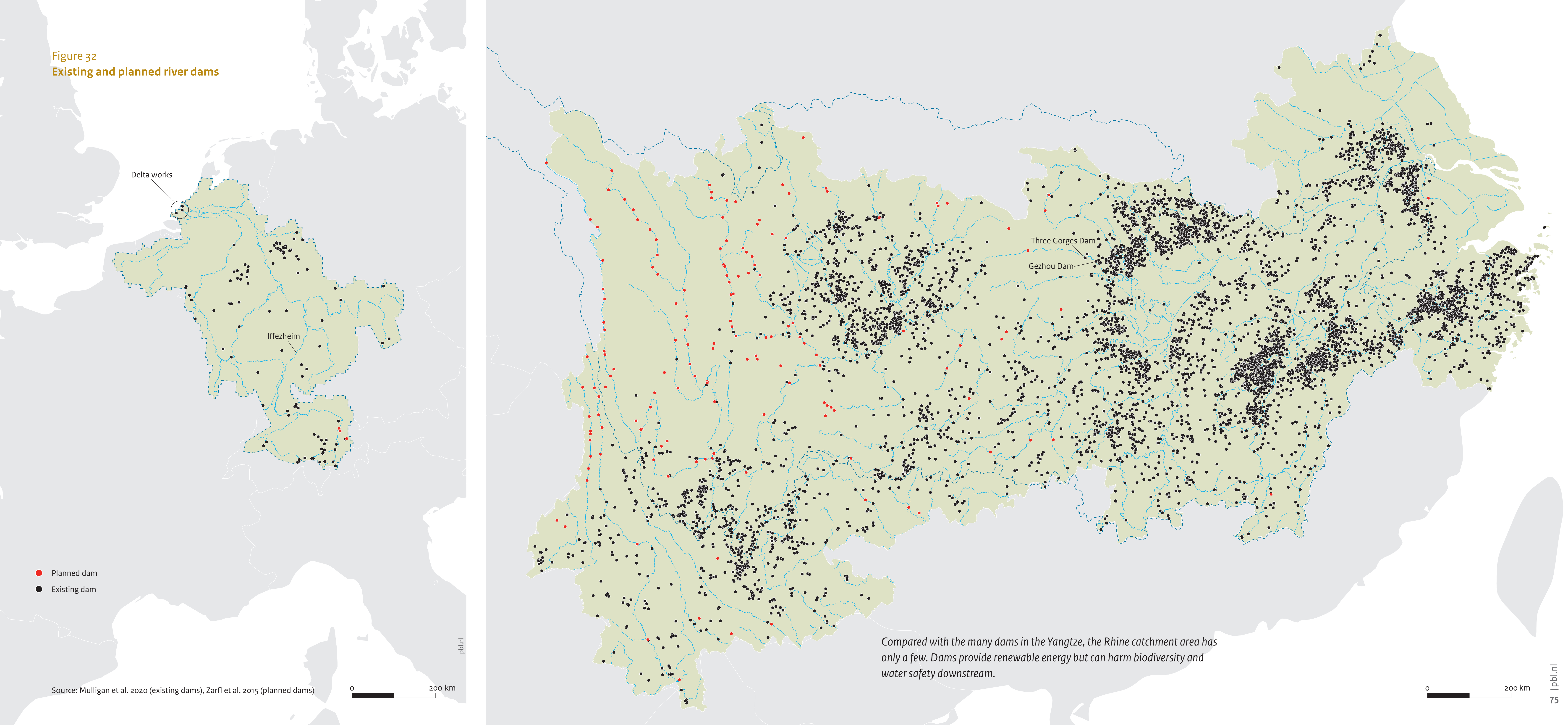
Figure 31
Water temperature anomaly for the Yangze River upper reaches



Source: Inglis 2016; adaptation by PBL

The average water temperature in the Yangtze has increased and will continue to do so, due to climate change.

Figure 32
Existing and planned river dams



Source: Mulligan et al. 2020 (existing dams), Zarfl et al. 2015 (planned dams)

Compared with the many dams in the Yangtze, the Rhine catchment area has only a few. Dams provide renewable energy but can harm biodiversity and water safety downstream.

In the Yangtze basin, the perhaps most important project to affect the river has been the construction of the Three Gorges Dam, which was completed in 2006. The dam provides 22,500 MW of clean power to the region and provides better navigability for barges that, therefore, are able to carry more than three times the previous weight in goods. Furthermore, the dam was built to also mitigate flooding for those downstream, which was especially important after flooding in 1998 left 14 million people homeless (Biello, 2008). The construction of the dam and reservoir first required the relocation of over 1.1 million people (Wu et al., 2004) and, after the was completed another 4 million were encouraged to move away from the area (Harris, 2011).

As with much infrastructural and 'single-focused' interventions for flood mitigation and industrial adaptability, the project has appeared to increase rather than decrease the impacts of flooding in the surrounding region. The dam has destabilised the land around it (Wu et al., 2004), possibly causing problems of drought through reduced water levels, for instance, at Dongting Lake (Huang et al., 2014; Li et al., 2018). From 1896 to 2019, Dongting Lake shrank by almost 50% (Yu et al., 2020) and, in recent years, the lake's dry season has arrived one month earlier than before (He et al., 2021).

Furthermore, the dam has caused a drastic decrease in sediments downstream, is leading to erosion on the coast, and has interrupted the movement of species that has led to biodiversity loss in the river (Wang et al., 2013; Tian et al., 2019). After the water impoundment of the Three Gorges Reservoir, the tidal zone of the Yangtze River estuary has significantly shifted upstream and the salinity levels in the estuary have also changed.

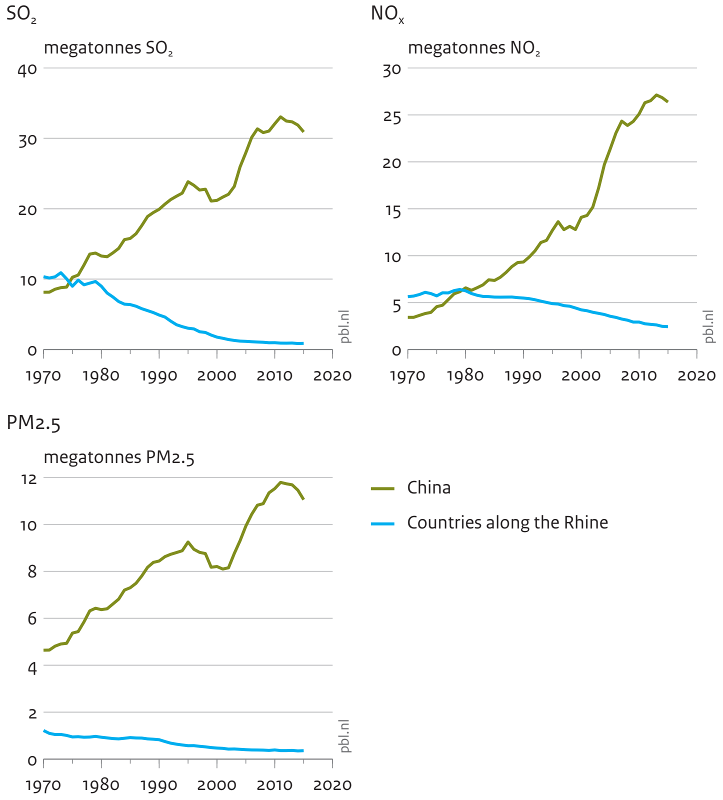
Dams between the North Sea and the rivers of the hinterland delta prevent the salty seawater from flowing inland. This is good for flood safety and agriculture, as the latter cannot thrive in salty or brackish water, but the lack of a brackish water environment is bad for biodiversity. Technical compromises do exist, such as the Eastern Scheldt storm surge barrier, but these are expensive. This wards off the sea water only in the event of a storm surge. In calm weather conditions, the sea water flows through, unobstructed.

4.2 Environmental policies along the Yangtze and Rhine

For centuries, river basins developed as places of urbanisation, industrialisation and agriculture, together with the pollutive side effects of these activities. However, large-scale developments of these phenomena in the 19th, 20th and 21st centuries have intensified and increased pollution and its consequences in river basins. The aftermath of large-scale pollutive incidents in the 20th century often forced the hands of governments to devise policies to limit the damage of pollution and other anthropogenic activities. The timeline, in this chapter, includes many international agreements aimed at reducing pollution and improving the environment.

Air pollution is a prominent issue in classical multilateral environmental agreements. The graphs in Figure 33, in line with the maps in Figures 25, 26 and 27, illustrate that air pollution has decreased in countries along the Rhine, between 1970 and 2015. China, where we observe a strong increase, is obviously in an earlier phase, compared to western Europe, when it comes to combating air pollution. For instance, acidification is no longer a significant issue along the Rhine, whereas in China, emissions of sulphur dioxide have increased since the 1970s. However, Figure 34 illustrates that sulphur dioxide, nitrogen oxides and particulate matter emissions have started to level down in China, around 2015, as well. For cities, this is a significant reduction.

Figure 33
Emissions of air pollutants



Source: EDGAR v5.0

The emissions of sulphur dioxide, nitrogen oxides and particulate matter have decreased in the Rhine River basin, but have increased in the Yangtze River basin. However, after 2010, a decrease in these levels has started off in the Yangtze basin, as well. These graphs illustrate that, compared to the Rhine, the Yangtze is in an earlier phase of addressing air pollution.

The Rhine and Yangtze basins differ, as far as the approach to water pollution is concerned. Along the Rhine, technology investments were made, such as in the collection of water from leakages and fire extinguishing, but businesses have remained in place. Along the Yangtze, in anticipation of the Yangtze River Law, many petrochemical companies were relocated, in addition to technical improvements. By 2016, there were over 400,000 chemical enterprises, 5 major iron-steel complexes, 7 leading oil refineries and mega-sized petrochemical works, and over 6,000 sewage outlets to the river. In 2021, however, all the 8,000 high-pollution factories were reallocated, and 1,361 illegal wharfs were removed or fully rebuilt. All the petrochemical works and iron-steel complexes were thoroughly transformed with green technology (MWR, 2021).

4.3 Case: Industrial Management And Control Along The Yangtze River

Many chemical plants have been built in the immediate vicinity of the Yangtze. The situation near Nanjing is exemplary for the establishment of the chemical industry along the Yangtze (Figure 34). Both national government and provincial government authorities are working to prevent the chemical industry from establishing itself in the vicinity of rivers in the future.

In 2017, five national ministries jointly published the 'Guideline on strengthening the green development of industries along the Yangtze River Economic Belt'. The guideline aims to protect the ecological environment of the Yangtze River basin, further improve the efficiency of the utilisation of industrial resources and energy, promote green manufacturing, reduce the impact of industrial development on the ecological environment and achieve green growth. One of its major objectives is to relocate hazardous chemical operations along the Yangtze River Economic Belt, as soon as possible. All 11 provinces and

Figure 34
Location of chemical plants (near Nanjing) along the riverbank of the Yangtze in 2019

Source Google maps

The riverbanks near Nanjing are illustrative for one of the objectives of the Yangtze River Protection Law to relocate chemical plants to locations further away from the river.

cities within the Yangtze River Economic Belt are required to implement this policy. Some of the local authorities have carried out specific policies or projects. These guidelines precede the 2021 Yangtze River Protection Law.

Chongqing Province adopted the national 13th five-year plan for the construction of ecological civilization, in 2017. According to the plan, the construction of new industrial parks within a 5-km radius of the Yangtze River and its main tributaries is strictly prohibited.

Jiangxi Province strictly controls the construction of new petrochemical and coal-chemical projects along the Yangtze. According to the ‘Three-year action plan for comprehensive improvement of the ecological environment of Poyang Lake (2018–2020)’, highly polluting enterprises with high emission levels in the downstream region will be strictly prohibited to relocate upstream. In addition, local governments prohibited the construction of new heavy chemical projects in the Jiangxi section, within a 1-km radius of the rivers Yangtze, Gan, Fu, Xin, Raohe and Xiu and the area around Poyang Lake. Under this prohibition, no new industrial parks with heavy and chemical industries will be issued construction permits within a 5-km radius of the Yangtze River.

The Hubei provincial government published and distributed the ‘Hubei province along the river chemical enterprise customs reform and transfer work plan’ in 2018. The plan aims to complete the transformation and relocation of chemical enterprises within a 1-km radius of the Yangtze River (including closure, transformation, relocation or conversion of production) as soon as possible, and, by 2026, to relocate all chemical enterprises that are currently within a 1–15 km radius of the river.

4.4 Case: Connecting ecological restoration and economic transformation at Emscher Landscape Park

Emscher Landscape Park is an example of an integrated regional project, in which, after the closure of the mining industry and many industrial complexes, nature restoration went hand in hand with investments in education and new economic drivers for employment, with the preservation of industrial heritage and the addition of new architectural icons.

The park is named after the Emscher river, a tributary of the Rhine that was used as an open wastewater system during the period of industrialisation. Emscher Landscape Park, a renewal programme aimed at the German Ruhr Agglomeration, was developed between 1989 and 1999. Its aim was transforming the previously heavy industrial area into a modern, green and vibrant area where people could live, work and enjoy recreational activities. Emscher Landscape Park took a holistic approach that included transformative urban, architectural as well as ecological, economic and social incentives (see Figure 34). The economic part was about replacing the mining industry by high tech green industry and new universities. The green and environmental aspects of this project were especially important since the area was formerly a place of coal and steel extraction that not only transformed the landscape, but also polluted air, soil and water.

The focus of the project was to restore the environmental quality of the 800 km² area, and to preserve the heritage aspect of the industrial character of the Ruhr region. The project reused industrial buildings also to achieve its social and recreational functions. The former coal mine industrial complex Zeche Zollverein obtained a UNESCO World Heritage status

Figure 35
The Emscher Landscape Park

Source: Regionalverband Ruhr, Essen, 2019

In the Emscher Landscape Park project, along the Emscher, a tributary of the Rhine, nature has been restored, industrial heritage has been conserved, along with investments in a new economy in this previously heavily industrialised area.

in 2001, and land art projects were added to the scenery. The project also cleaned up the Emscher river, which channelled waste water into underground canals. The residential programme of 6000 dwellings has been relatively small.

Approximately 118 projects have been carried out in 10 years' time. In total, 2.5 billion euros were invested, 60% of which in public investments and 40% in private investments.

4.5 Findings on the environment and biodiversity in the river basins

Both pollution and the decline in biodiversity are severe in the two river basins. Industrial pollution in the Rhine basin has been considerably reduced and a similar reduction has been started in the Yangtze basin. In both basins, today's pollution includes chemicals and air pollutants from combustion processes. In both catchments, nutrients that are mainly from agriculture are a persistent problem due to legacy pollution. It is difficult to restore biodiversity. This also has a spatial component, as habitats have been reduced or parcellated (e.g. by road infrastructure or hydropower stations) and riverbanks are no longer in their natural state.

The cases show different approaches to reducing pollution and restoring biodiversity. Under the Yangtze River Law, the scale of the river basin prevails over the regional scale with respect to policies and, therefore, enables nature restoration and prevents pollution, for instance, by relocating industry away from the riverbanks.

Emscher Landscape Park illustrates a situation where industry has already declined and where, in a regional plan, a new service and high-tech economy was stimulated along with nature restoration and the conservation of industrial heritage. All contributing to a positive image of the formerly deprived region.

The next chapter describes how the construction of water works also affects flood risk in river basins.

Climate change adaptation in the Yangtze and Rhine River basins

5

长江与莱茵河流域的气候适应

Because of climate change, flooding events are expected to increase in impact as well as frequency. This chapter maps the areas at risk and shows the interplay between urbanisation and water works on the one hand, and flooding and climate change adaptation on the other. Especially new concepts of climate change adaptation have a spatial impact.

5.1 Increasing floods and more extreme weather conditions

Climate change will cause sea levels to rise, and the frequency of extreme weather events inland, especially downpours, will also increase, further adding to the risk of flooding. Severe flood risks are to be found at the middle and lower courses of the Yangtze and Rhine River basins (Figure 36). Without embankments and coastal defences, a large part of the Netherlands would be permanently inundated. For the Yangtze River basin, a relatively small area is at risk of coastal flooding. However, on the Chinese seaboard, typhoons are important, regular phenomena and their frequency is prone to increase as a result of climate change.

Settlements are vulnerable to flooding, and this is especially true along rivers and in river deltas, where settlements and economic activity are concentrated. Moreover, surface sealing, caused by urbanisation, exacerbates the flood risk by increasing runoff from rainfall. Of course, cities and countries situated in flood-prone areas have built infrastructure to prevent flooding and to alleviate the negative effects on the social and economic activities along riverbanks.

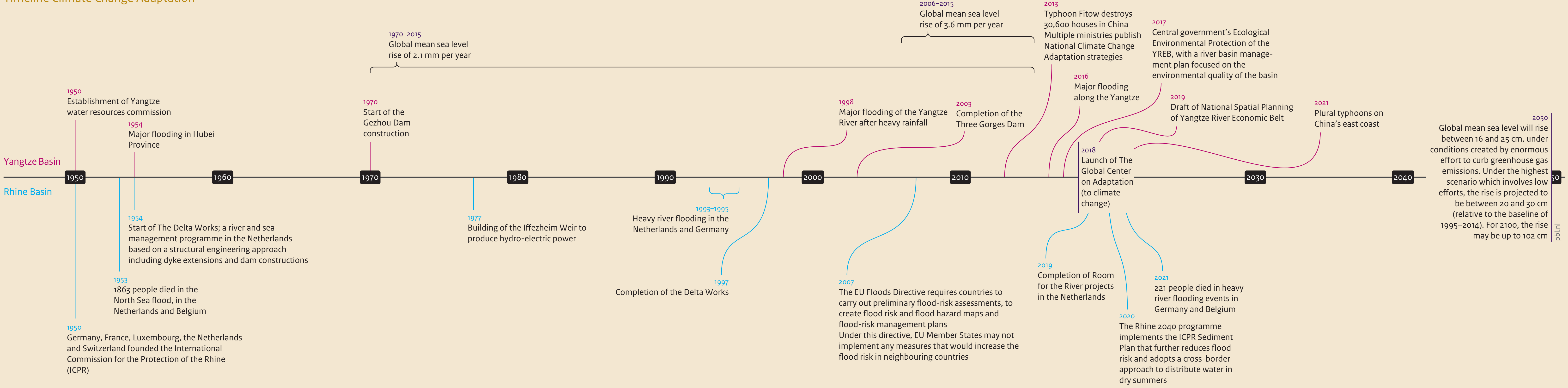
Dams and restrictive water infrastructure interrupt the flow of sediments in a river and deprive areas downstream of the sediments that are necessary to maintain coastal areas. This has consequences not only for the ecosystem and the water quality, but also for the risk of coastal flooding.

5.2 Changing water discharges

The Rhine and the Yangtze are both partly glacier rivers. Their water principally comes from snowmelt at the source of the rivers. Meltwater from the ‘water tower’, i.e. water storages in glaciers and other snow and ice surfaces in the mountains, usually mitigates the ups and downs of snowfall in the mountains. The diminishing of the ‘water towers’ due to global warming will eventually lead to a reduction in freshwater provision to rivers and lakes downstream.

Because of an increase in evaporation due to rising temperatures, there will be less water in the rivers in general, but in times of heavy rainfall, the peaks will be higher. This shift is creating more rapid changes between water levels, with lower levels creating problems for shipping and higher levels increasing the risk of flooding. On average, river discharges

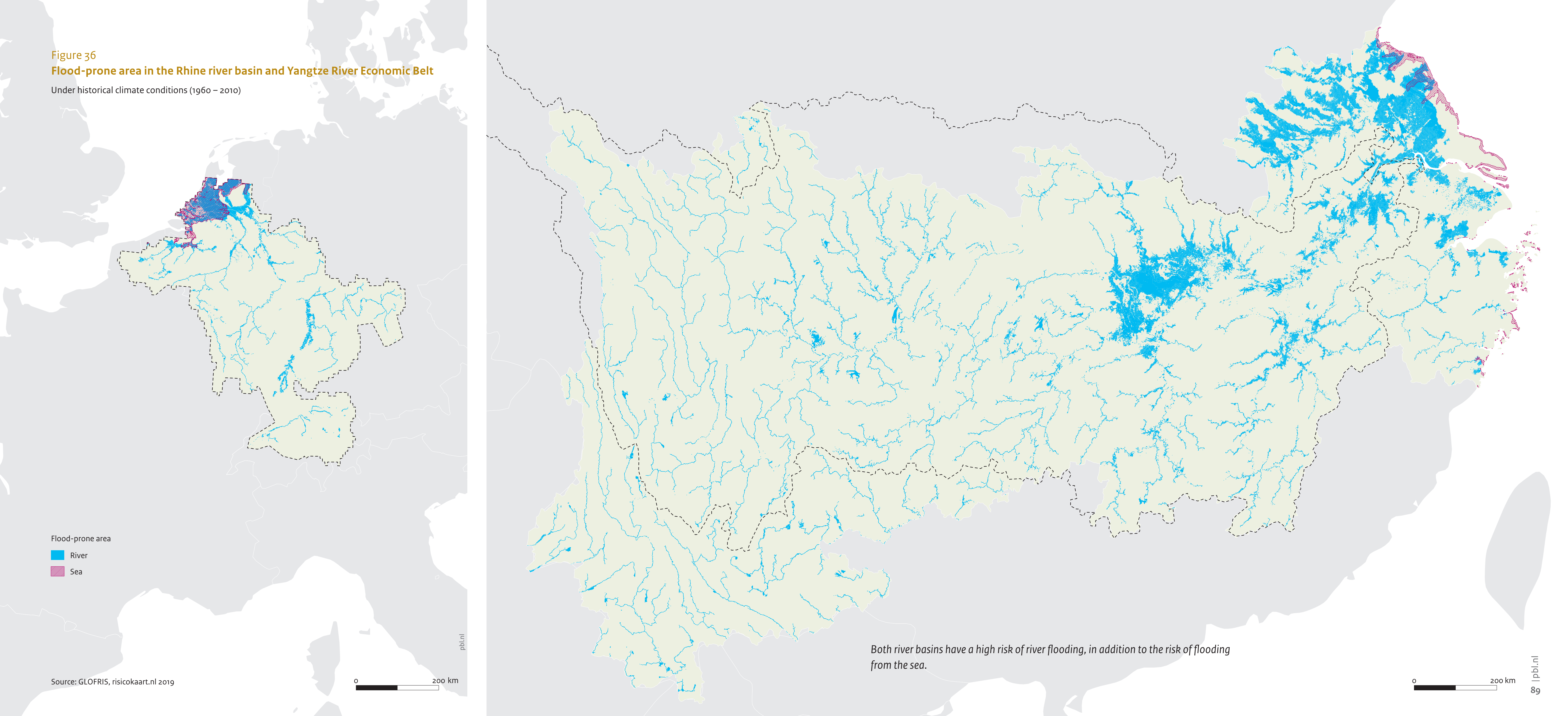
Timeline Climate Change Adaptation



Source: PBL

Figure 36
Flood-prone area in the Rhine river basin and Yangtze River Economic Belt

Under historical climate conditions (1960 – 2010)



Both river basins have a high risk of river flooding, in addition to the risk of flooding from the sea.

Source: GLOFRIS, risicokaart.nl 2019

decrease in all months and, for the Rhine, the seasonality will become much more pronounced in the future as the river flow in late summer generally will be half that of the present day (Figure 37).

Low water levels can impede shipping, reduce the supply of fresh water for drinking and irrigation, increase water temperature, increase the concentration of pollution and harm biodiversity.

5.3 Governance on Climate Adaptation

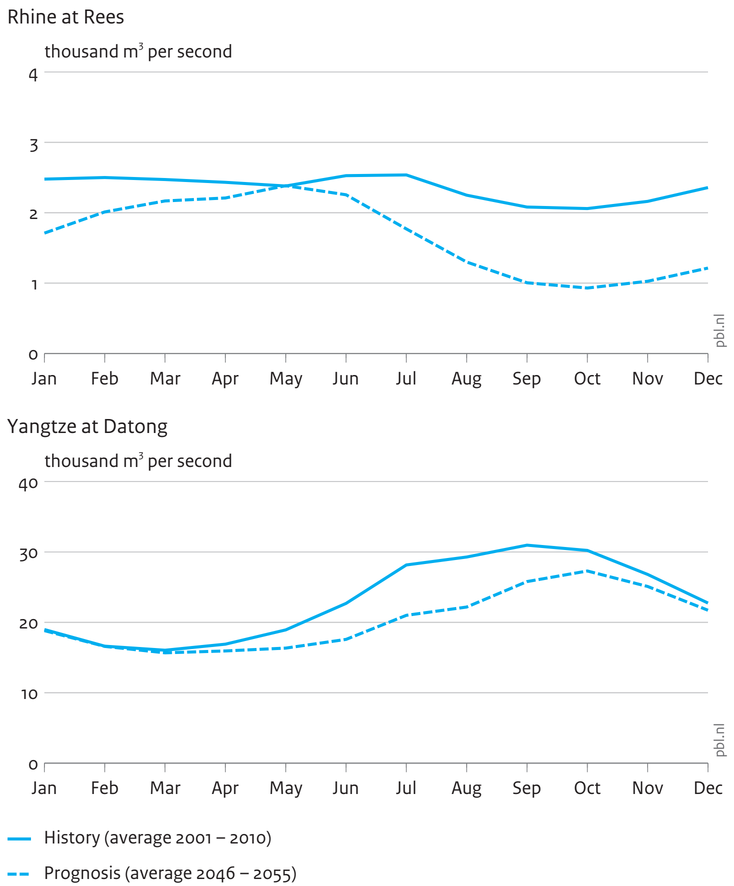
5.3.1 Water works from a historical perspective

China has a long tradition of harnessing its rivers. An example is the Grand Canal, of which the oldest parts were already dug in the fifth century BC. This canal of 1794 kilometres connects Hangzhou in the Yangtze Delta with Beijing in the north. Since the Han dynasty, farmers have been constructing embankments in the Yangtze River basin.

Along the Rhine, people have been constructing embankments and settlement protection since the Middle Ages. However, major and comprehensive flood protection projects to protect settlements did not truly start until the 19th and 20th century (Uehlinger et al., 2009).

Changes to the river flow and the natural spillover areas have led to an increase in flood risk and sediment restrictions, especially downstream from the Iffezheim Dam. In addition, following the major floods of 1953, the Netherlands started construction of the **Delta Works**, a major flood-control programme that partly closed off the Rhine, Maas and Scheldt from the North Sea.

Figure 37
River discharge



Source: PCR-GLOBWB 2

Because of climate change, future river discharges will be significantly lower, especially in the Rhine. This will impact shipping, freshwater supply and biodiversity.

5.3.2 New approaches to climate adaptation

After almost half a century, the Dutch Delta Works were succeeded by a more comprehensive governmental approach, the *Delta Programme*, with a long-term view to protect the Netherlands from future flooding and to ensure drinking water for the country. The *Delta Programme* has a time horizon of 100 years, thus enabling interventions over time and space, with costs being spread over a long period and linked to, for example, regular maintenance.

Newer climate adaptation strategies look to anticipate and adapt to water flow and environmental changes rather than try to restrict or prevent them. Newer infrastructure must also be adapted to the multiple uses of water and prevent the negative effects downstream that relate to either too much or too little water. For example, the *Room for the River* strategy, which extended the floodplains around certain areas of the Dutch part of the Rhine in anticipation of infrequent large increases in water levels.

Recently, China has developed infrastructure that is designed to work with nature rather than simply resist or divert water flow. The sponge city initiatives look to solve both the problem of water scarcity and that of flood risk created by impermeable surfaces in cities. The new infrastructure is aimed at collecting and diverting rainwater for urban agricultural projects and building rooftop gardens and replacing concrete with bioswales to solve the problem of impermeable urban surfaces (Harris, 2015). In China, sponge city initiatives have been rolled over 30 cities in China, including Shanghai, Wuhan, Chongqing and Shanghai. 'By 2030, participants must ensure that 80% of their urban land includes sponge features.' (Jing, 2019).

5.3.3 International commissions to coordinate Rhine Water Management

After the floods in 1993–1995, the ICPR, which had been coordinating environmental issues and mutual access between the Rhine riparian states, sought to address the fact that major infrastructural and canalisation projects were at least partly responsible for the floods. Its mandate was extended to include flood-control measures. As a result, countries along the Rhine have instituted their own flood and climate adaptation programmes, such as the Dutch 'Room for the river' initiative. Germany implemented the project 'Lebendiger Rhein — Fluss der tausend Inseln' which takes multiple measures to improve the Rhine, and France implemented 'LIFE: Rhin vivant' aiming at revitalisation of the river.

International river commissions have also been established for the Meuse and Scheldt. So far, these have been less successful than the Rhine Commission. This is in part due to the fact that they have a shorter history of international cooperation, but mainly because there are disparate interests at play in the Scheldt. The rivalry between the Port of Antwerp and Port of Rotterdam hinders administrative agreement on ecological issues (De Vries et al., 2007).

5.3.4 The Yangtze River Protection Law

The Yangtze River basin management has a long history, perhaps spanning as far as the construction of the Grand Canal, in 500 BC, linking Beijing, the Yellow River and the Yangtze. More recently, since China's 'opening up and reform', river basin management has overwhelmingly been managed by the central government, conducted through the Ministry of Water Resources. In some ways, it seems that the Yangtze River basin management is simpler than that of the Rhine, as it is contained within one country's borders and does not have to be negotiated between countries. Nevertheless, the intensive and condensed process of market liberalisation has put considerable pressure on the ecological well-being of the Yangtze River basin and has unveiled the weakness of the current system when it comes to protecting the river.

From the 2010s onwards, China has not only improved the ecological and environmental condition of the river basin but has also changed its policy towards a more integrated river basin management plan to control negative intra-basin effects. In 2017, the central government unveiled the Ecological Environmental Protection of the Yangtze River Economic Belt — The Yangtze River Law. It is a river basin management plan focused on the environmental quality of the basin, through measures such as improving local regulations on environmental protection and the implementation of information disclosure which allows ministries access to up-to-date information and educational plans to promote the ecological literacy of the population. It is for the first time that China manages one river basin under one law. For the implementation, over 100 river chiefs along the Yangtze river and its tributaries have been appointed by the state. Each of them is responsible for a part of the river basin and has the power to overrule provinces. The law came into force in 2021.

5.4 Case: Room for the River - Nijmegen, the Netherlands

The Room for the River policy plans in the Dutch city of Nijmegen are exemplary for the new approach of working with water rather than fighting against it. In this project along the Waal River, which is a branch of the Rhine, water safety is combined with new housing plans, recreation, and nature development.

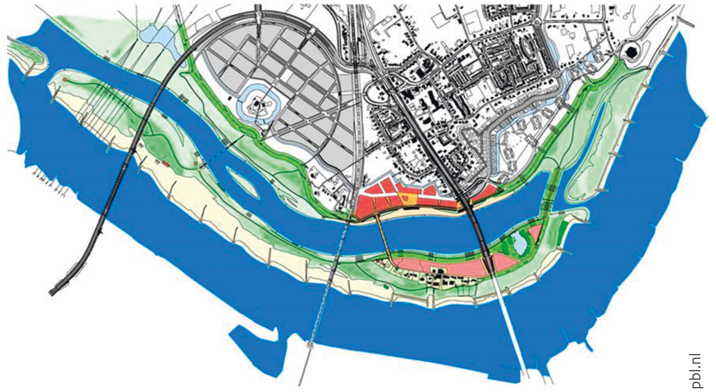
In the Netherlands, the floods of 1993 and 1995 casted doubt on the approach to flood prevention at that time, namely that land reclamation and building dykes and embankments were positive techniques in water management. The events of 1993 and 1995 revealed serious problems with this idea of creating infrastructure to keep water out. Subsequently, a newer approach was considered; rather than restricting water, the area around the river could accommodate fluctuating flows.

As part of the Delta programme, Room for the River restores the river's natural floodplain in certain areas to accommodate higher water levels and flows, to better protect other, built-up areas. This is done in a combination of over 30 measures, by which, for example, the floodplain will be lowered, broadened and/or river emergency by-passes and temporary water storage areas are created. Marshy riverine landscapes have also been restored to protect biodiversity and aesthetic value.

One of the Room for the River projects exemplifying environmental adaptation is the 'Room for the Waal' project in Nijmegen (Figure 38). Here, the embankment on the northern side of the city was moved 350 metres inwards and an ancillary channel was dredged in the floodplain to help accommodate river flow during periods of high water. This procedure required relocating some of the inhabitants from the flood channel. While there was local opposition to the project, residents were financially compensated for their required relocation.

This measure was especially necessary because the river Waal near Nijmegen takes a sharp bend, forming a bottleneck for the water, posing a flood risk for the area during high tide. The project of moving the embankment had a double goal of protecting the city against flooding and improving the spatial urban quality. Building the channel created an island, which forms a city park for Nijmegen with urban development possibilities.

Figure 38
Room for the Waal, Nijmegen 2020



Source: Nijmegen municipality

Design Variant for Nijmegen's Room for the Waal, including the ancillary channel, the island and new residential developments.

Room for the Waal required cooperation between many administrative levels: national, provincial and municipal, and combined ambitions for housing, recreation, flood protection and nature. Rather unusual for a flood defence project of this scale is the fact that the project was entirely funded by the central government, while the municipality of Nijmegen was entirely responsible for planning and carrying out the project because of its urban location and function. The result is a multi-functional flood defence infrastructure that combines recreation, nature reserve, housing and transport infrastructure to the city of Nijmegen.

5.5 Case: Wuhan, the city of a hundred lakes

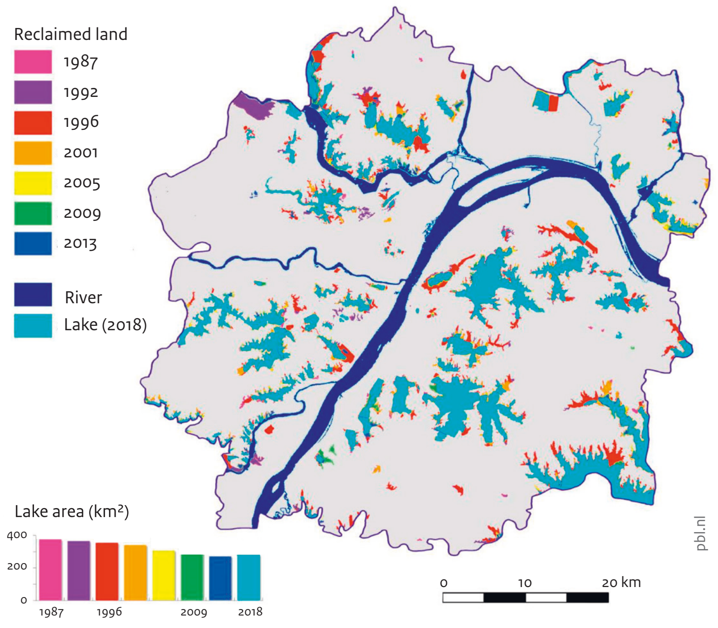
Wuhan, the city of a hundred lakes, is the capital of China's Hubei Province and has over 11 million inhabitants. The Yangtze flows through the city in a remarkably flat, wide landscape. In the 1950s, there were 127 lakes in Wuhan, while, in 2019, this had dwindled to 38. Efforts are made to bring the lakes back to Wuhan to improve the city's water retention capacity.

The urban area of Wuhan began to expand significantly between the 1970s and the 1990s. In the 1970s, there was little government oversight on maintaining the lakes' water level. Lakes were mainly transformed into land for agricultural use. At this time, the total lake area decreased by nearly 30%, and large lakes became fragmented. In the 1980s, the government began to strengthen the management of the lakes and some farmland was reconverted back into lakes. In the 1990s, however, Wuhan experienced a real estate development boost and lakes were filled with water again (Wu et al., 2019).

From 1991 to 2010, the water area of Wuhan decreased by 38% (see Figure 39). Since the year 2000, the municipal government started to implement measures to protect the lakes, under the Wuhan Lakes Protection Regulations. This law, along with its strengthening in 2005, has been successful at slowing the reduction in lakes in Wuhan (Wu et al., 2019).

In 2009, the government began to regulate real estate development and urban expansion in Wuhan, and, in 2014, the city started urban renewal programmes which further slowed down the reduction in lakes. In 2018, the government rolled out the idea to build a regional ecological network. Since 2015, Wuhan is one of China's 'sponge cities', a central government project to make cities more flood-resistant. The idea being that

Figure 39
Lake evolution of Wuhan urban development area, 1987–2018



Source: Wu J. et al. 2019

Wuhan's lakes have been steadily shrinking due to land reclamation for agriculture and urbanisation, with major consequences, such as for water safety.

by preserving blue and green space, developing low impact development and improving the water infrastructure, Wuhan will comprehensively improve the ability to cope with rain and flooding. So far, more than 38 km2 have been retrofitted to include permeable and 'sponge' infrastructure. By 2020, the city was to include 20% of urban land with sponge features, which should be 80% by 2030 (Jing, 2019).

5.6 Findings on climate adaptation in relation to river basins

Increasing urbanisation is at odds with increasing flood risks because riverbanks are common settlement locations. Urbanisation, with surface sealing as a result, is also contributing to an increase in flood risk, especially during heavy rainfall. In time, the canalisation of rivers and many dams will also further increase flood risks downstream by retaining silt that is necessary to compensate for the natural erosion of delta areas. Instead of building higher and higher embankments for protection, new approaches to flood prevention are being applied, working with water rather than against it — for example, by retaining the water longer and giving the rivers more space.

Both cases illustrate this new approach of allowing the rivers and lakes to use more room for flooding instead of encapsulating them. The 'sponge city' concept focuses on retaining water on a local level. In the examples of Wuhan and Nijmegen, biodiversity, water quality and liveability take advantage of the 'sponge city' approach.

Of course, climate adaptation goes hand in hand with climate mitigation. The next chapter explores the efforts to decarbonise the two river basins.

6

Decarbonisation in the Yangtze and Rhine basins

长江与莱茵河流域的脱碳

To alleviate climate change, it is necessary to reduce the emission of greenhouse gases. This chapter shows the sources and types of consumption of energy and the emission of greenhouse gases, over time, in both river basins and list fossil-free alternative options. At the end of this chapter, we will take a closer look at the role of port cities in decarbonisation.

6.1 From a fossil-based industrial revolution…

Historically, an important part of the Rhine basin was an area for mining and energy production. Before the 19th century, most mining and industrial activities were small scale and local. With the development of the coal and iron industry in the 19th century, industrialisation and urbanisation expanded drastically within the river basin (Uehlinger et al., 2009). This was especially the case in Germany, with production primarily located in the Ruhr Valley and Saarland. In the 1950s, the coal industry plunged into crisis and was replaced by oil (and later by nuclear energy). Oil imports were established at the Port of Rotterdam. Steelmaking went through a similar crisis in the mid 1980s. The subsequent turnaround left some agglomerations profoundly changed (see the Emscher Landscape Park case).

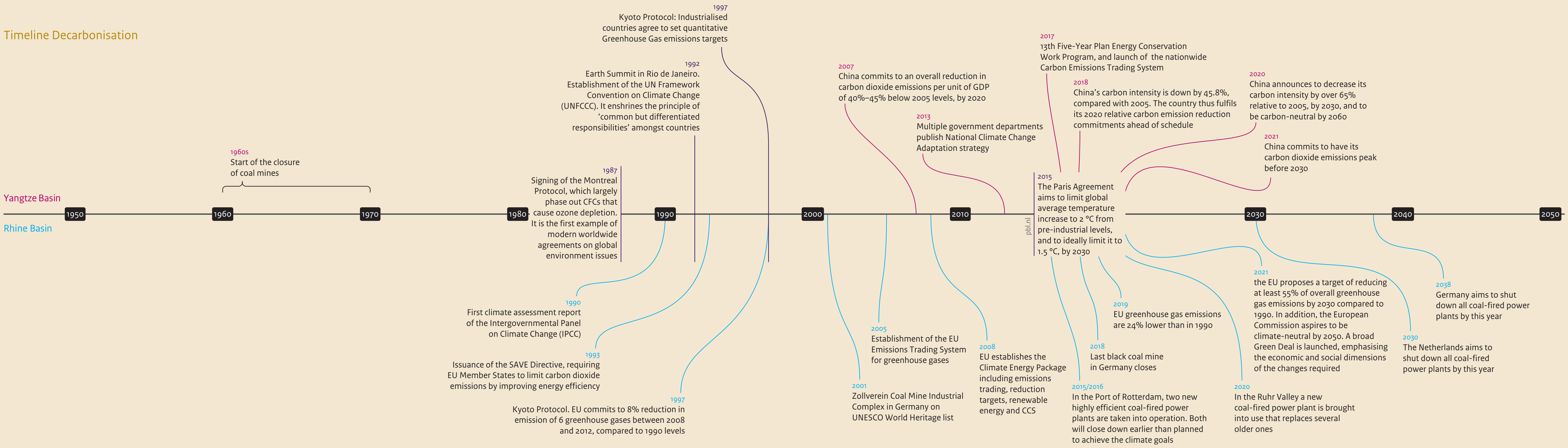
Industrialisation in the Yangtze River Economic Belt has happened more recently in comparison to the Rhine basin. China gained prosperity from its manufacturing industries along the coastal areas that developed mostly in the 1990s and 2000s. This development expanded towards the hinterland in the 2000s. The Yangtze basin provides good access to the interior of the country and, thus, cities along the Yangtze were the subject of additional economic and urban development.

This economic development went hand in hand with the increases in greenhouse gas emissions. The locations of greenhouse gas emissions follow the urbanised areas and, therefore, also the rivers (Figure 40).

6.2 …to an energy transition away from fossil fuels

As part of climate change policies, many new approaches to energy production have been initiated in the Rhine and Yangtze regions. Carbon-neutral and low-carbon energy production methods, such as nuclear energy, hydropower, biomass, hydrogen, solar and wind, are beginning to see implementation or are considered (see the text box on Energy transition). However, the transition to fossil-free energy sources often comes with challenges, often associated with future development of the regional economy, the quality of urban development and large investment networks. All options require the involvement of many players at various government levels and market parties. The economically dense basins of Yangtze and Rhine give an excellent view on these developments, strategy building, and experiences along the way.

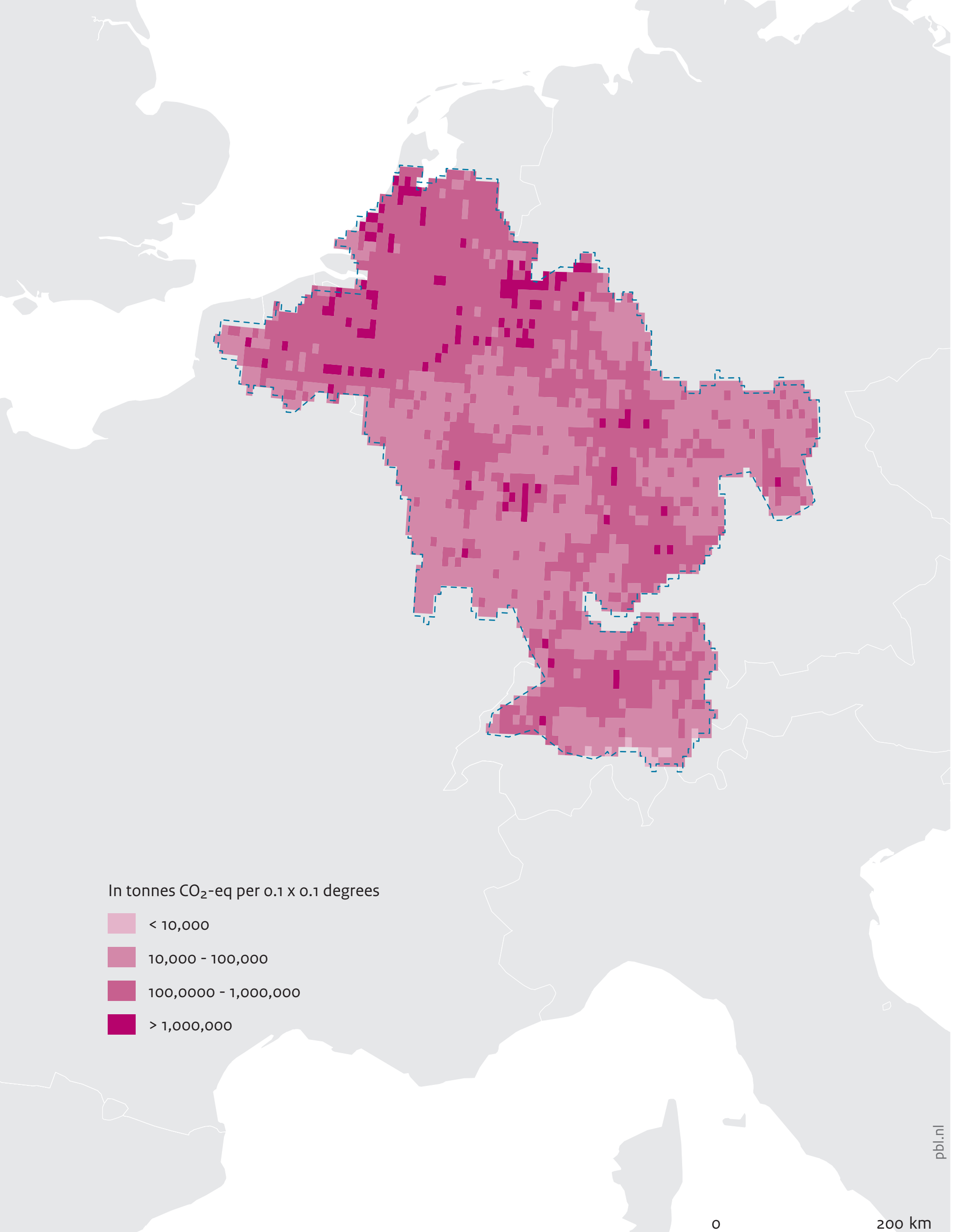
Timeline Decarbonisation

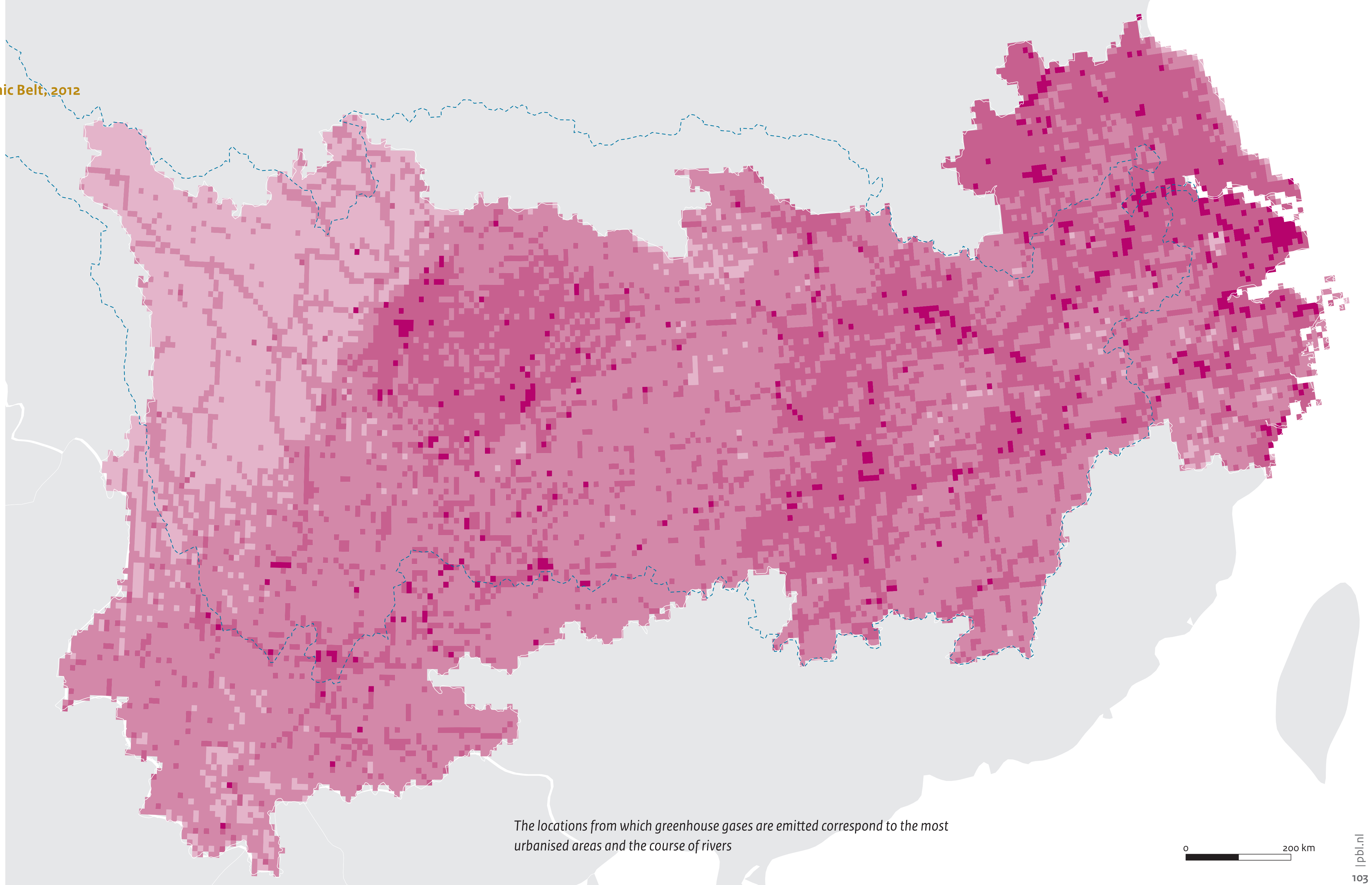


Source: PBL

Figure 40

Greenhouse gas emissions in the Rhine river basin and the Yangtze River Economic Belt, 2012

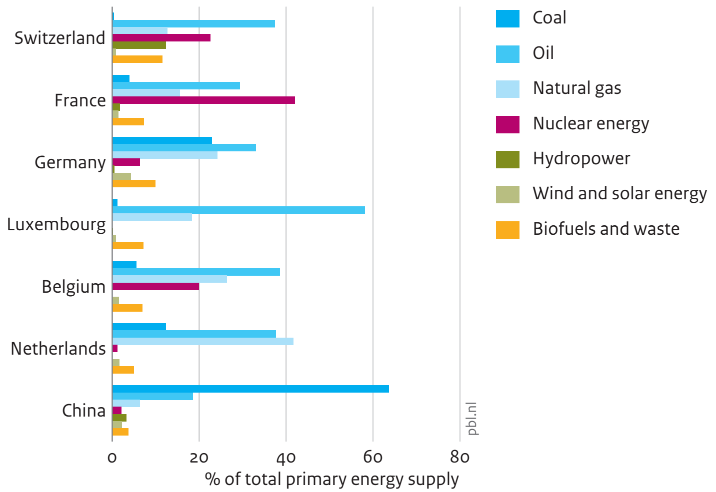




Source: EDGAR v4.3.2

The locations from which greenhouse gases are emitted correspond to the most urbanised areas and the course of rivers

Figure 41
Primary energy supply, 2017



Source: IEA

China's energy supply is largely dependent on coal. In the Rhine countries, the share of fossil fuel is smaller, partly because of the large shares of nuclear energy.

Notwithstanding their similarities, the two basins differ significantly in energy sources and energy. For their energy production, China and the Rhine countries rely on fossil fuels, as indicated in blue in Figure 41. This figure shows the scale at which fossil energy production must be replaced by renewable energy. It also shows that this can vary enormously, from country to country, in the Rhine River basin, depending on the availability of hydropower, wind and solar power or the deployment of nuclear power plants. In the Yangtze, a large amount of the energy used remains fossil-fuel based (and especially coal-based) (Figure 40). For instance, in 2021, China had over 1000 GW in coal power capacity and a further 250 GW planned. China counts 341 active coal mines and a further 133 coal mines are being planned (Global Energy Monitor, 2021).

Energy transition

A host of key technologies feature in the energy transition:

Nuclear energy presents a hard-to-avoid alternative to presently important fossil fuels. However, it also has its own problems. Perhaps most evident is the risk of nuclear disaster such as those at Chernobyl or more recently, Fukushima, which have created public unease with this type of energy generation. The second problem is that of the storage and disposal of nuclear waste, which according to its proponents could be buried in deep geological repositories. But this option, again, is often not popular.

Hydropower also presents ecological trade-offs. Aside from land and landscape that is sacrificed, important problems stem from dams preventing the flow of sediments essential for maintaining fertile land in the river basin and the maintenance of natural flood defences. In addition, there are problems associated with dams acting as barriers for aquatic biodiversity.

Wind and Solar energy are on the rise in Europe, with, in 2020, wind power accounting for 14% and solar power for 5% of the energy produced (in EU-27) (Agora Energiewende and Ember, 2021). However, the locations of wind farms and solar meadows may encounter a lack of public support, such as for aesthetic reasons and noise nuisance, but also because solar meadows leave little room for biodiversity. On the other hand, wind farms at sea and solar panels on roofs hardly cause any protest.
In times without wind, hydropower can be generated with water from a reservoir that can be filled in times of high wind. Such a reservoir then functions as energy storage.

Geothermal energy is another renewable source of heating and cooling and, in the case of deep geothermal energy, the generation of electricity. Deep geothermal heat uses the heat from the subsurface of the earth. The advantages of geothermal energy are its security of supply and the nearly unlimited availability. In volcanic areas, geothermal energy comes close to the surface and is relatively easy to exploit. Other areas depend on deep geothermal energy, which is less profitable to exploit. The construction of heat networks with residual heat from industry can help to anticipate the future exploitation of deep geothermal energy.
Other key technologies would primarily have a role in the transitional phase and perhaps less so in an eventual low-carbon energy system. Important amongst these are energetic use of biomass and carbon capture. Both have implications for industries, ports, and related infrastructure in river basins such as those of the Yangtze and Rhine.

Biomass is an important resource for the near-term changes in energy production away from fossil fuels. Biomass energy is derived from advanced woody crops, residue from agriculture and forestry, and biological waste streams (from the food industry, sewage or households). It accounts for almost 60% of the renewable energy used in the European Union and is mostly sourced (96%) within the EU itself (Scarlat et al., 2019). Large shares of biomass consumption are encountered in Germany and Switzerland. Liquid and solid biomass can also replace oil for the chemical industry in the production of plastics and other products, through the production of chemicals such as ethylene and methanol. The sustainability of mainly woody biomass is heavily disputed by some interest groups (Strengers and Elzinga, 2020). Different types of biomasses are likely to play a role in the energy transition and in several applications that, otherwise, have limited possibilities to decarbonise (i.e. heavy transport, bio-kerosene, marine transport and feedstocks for chemistry).
An end-of-pipe decarbonisation technology is that of carbon capture and storage (CCS). CCS is the technique for trapping carbon dioxide emitted from large point sources such as power plants, compressing it, and transporting it to a suitable storage site where it is injected into the ground (European Commission, 2109). Carbon capture and utilisation (CCU) is like CCS, but instead of storing the carbon, it is used to directly create products (e.g. plastics), avoiding most of the carbon emissions of traditional production processes.
Technologies such as CCS provide a part solution to carbon emissions, at least in theory, and probably not forever. There is opposition to CCS from environmentalists, because the technology does not incentivise the reduced use of fossil fuels, and thereby delays the development of renewable energy sources. (Bakkes et al., 2017). CCS is also criticised because of its overall effect on energy use; compressing the carbon dioxide and pumping it into its underground storage requires considerable energy, i.e., more fuel. A third factor is the local opposition that originates from the fear of the type of problems traditionally associated with mining activities and gas extraction. In theory, a great strength of CCS is that it can be combined with biomass burning, for example in a power plant, resulting in negative carbon emissions. This should be seen as a temporary option, as storage capacity is fundamentally limited and not every location is suitable.

Hydrogen, although not an energy source, is potentially a key energy carrier because it can be stored and transported along existing networks (with some modifications to those networks). In addition, it can be employed in the fossil-free variants of industrial processes, such as steelmaking.

China has taken great strides in investing in wind and solar energy, but in 2017 coal remains by far the most important energy source (over 60%). Amongst the Rhine countries, coal use remains sizeable in Germany (with just over 20%) and the Netherlands (with just over 10%). Nowadays, coal is used to a lesser degree in the Rhine countries, but other fossil sources of energy remain important for the Rhine countries (oil and natural gas). In terms of non-greenhouse gas emitting energy sources, nuclear power is the largest share of energy supply in the Rhine countries, especially in France (with just over 40%) and Switzerland (with just over 20%). Finally, in terms of other non-fossil energy sources, biofuels are the most important, yet much less significant than nuclear, with the largest shares in Switzerland (just over 10%) and Germany (10%). Hydropower, wind and solar power have relatively small shares, except hydropower in Switzerland (just over 10%).

China has included CCS and CCU technology in its 12th and 13th five-year plans. However, CCS and CCU are still in the research and project implementation phase. Barriers remain, such as a lack of information and funds to rolling out this technology in China (Jiang et al., 2020).

In the Netherlands, a project near the city of Rotterdam, which planned to store 10 million tonnes of CO_2 over a period of 25 years in a depleted gas field, was cancelled due to local opposition to the project (Limousin, 2010). In current Dutch CCS plans, CO_2 will be stored in empty gas fields under the North Sea, thus avoiding objections from residents.

When comparing the economic potential between the Yangtze and Rhine basins, four common aspects of the above technologies stand out:

- The increasing and changing role of networks (gas, electricity, heat) — intimately connected to decisions about investments and location.
- Location-bound decisions in a crowded and dynamic area, often amidst a polarised public debate. Close connections to manufacturing industry and port facilities.
- A large amount of strategic thinking is still going on, in this area, involving various layers of government as well as market parties. Comparing strategies and experiences along the Rhine and Yangtze may therefore provide new insights.

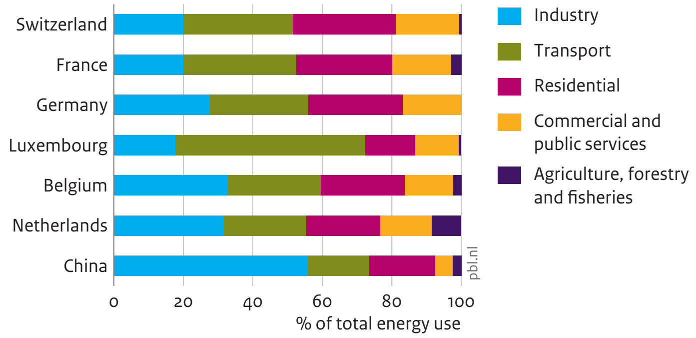
Besides industry and transport, the residential sector is a large energy consumer (Figure 42). It accounts for around 25% of final energy consumption in the European Union, which means it is an important subject for EU energy policy. In China, more than half of the energy is used by the industrial sector, reflecting the difference in economic activity between the countries in this comparison. Along the Rhine, we see subtle differences between the countries. The Netherlands has a relatively large share that is used in agriculture because of the large amount of greenhouse horticulture. Luxembourg has a large share used in transport because of its low petrol prices, attracting buyers from neighbouring countries which are only a short distance away.

6.3 The longevity of fossil-based infrastructure

Long-lived structures often form an obstacle in reaching emission-reduction goals. These long-lived structures include transport routes, refineries, and power generation infrastructures (such as coal-fired power plants). This is not only because these structures are costly to install and represent large sunk costs, but also because the services they provide become essential to the surrounding population.

It is necessary to examine how this existing infrastructure can be used for renewable energy. Ports, as a location, starting point or end point for this infrastructure, can play an important role here, if only because of their strategic location, but also in connection with the question of whether energy complexes can possibly be converted.

Figure 42
Final energy consumption per sector, 2017



Source: IEA

Most of the energy used in China in 2017 was in industry. In the Rhine countries, the share of transport in energy use was relatively high.

The transition to fossil fuel-free ports will certainly have a spatial impact, since oil is stored in compact oil terminals, and the storage of other energy carriers, such as biomass (bulk) is more extensive, mostly due to its slight energy density.

6.4 Climate policies towards zero emissions

In the face of climate change, national governments have put measures in place, or pledged to do so, to minimise the emission of greenhouse gases. Greenhouse gas emissions present a serious decision point for many countries, as many believe that traditional industrialisation, rising GDP, and subsequently higher living standards are necessarily linked to increases in greenhouse gas emissions and, therefore, a historical right to emit and thus to contribute to further global warming. Importantly, many of these countries are situated in Southeaast Asia.

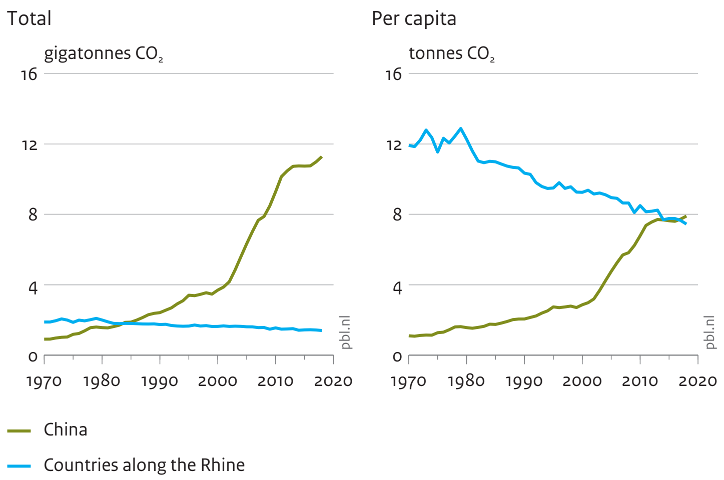
In 19th and early 20th century, there were hardly any regulations on emissions, which is why the environmental and ecological conditions of the river basins deteriorated. Regulations on greenhouse gases did not exist. Recently, awareness of the negative effects of carbon emissions on the environment has, amongst other things, further propelled countries to transition towards the use of renewables as sources of energy.

In the 2000s and 2010s, the amount of carbon dioxide emissions has slowly decreased in the countries along the Rhine, whereas emissions in China have increased (Figure 43). The European Union managed to reduce its greenhouse gas emissions over the last two decades. In 2017, its share of energy from renewable sources increased from 8.5% in 2004 to 17% in 2016 (Amanatidis, 2019).

China's greenhouse gas emissions increased nearly 6.6 times, between 1970 and 2015 (Crippa et al. 2019). China's annual CO_2 emissions saw an increase in 2018 of 1.5% (Crippa et al., 2019). Per capita, however, and nationally averaged, China's emissions have long been on a significantly lower level than those in the Rhine countries.

For the European Union, the struggle to reduce the largest sources of emissions largely lies in transport, industry and power generation. Indeed, transport is the only EU sector where greenhouse gas emissions increased, since 1990 (Pernice and Debyser, 2019). For the European Union, one of the main challenges is to maintain equal and increasing mobility through transport while decreasing transport related greenhouse gas emissions. As it does not intend to reduce the levels of

Figure 43
CO_2 emissions



Source: EDGAR v 6.0, OECD

Carbon dioxide emissions in the countries along the Rhine are slowly decreasing, while they are increasing in China. Along the Rhine, per-capita emissions have long been much higher than in China. In 2020, the per-capita emission level is about the same in both regions.

transport along busy transport corridors, so as not to disturb economic growth and activity, the approach to decarbonisation is not to reduce activity but to technically change it. Electric vehicles will play an important role here (as soon as electricity production is largely fossil-free).

The instrument of carbon pricing encourages the reduction in greenhouse gases emitted into the atmosphere; it usually takes the form carbon tax, often in combination with trading in carbon emission rights. The Kyoto protocol established a set of market-based principles to achieve its targets including 'emissions trading' and joint implementation (Prahl et al., 2014).

The EU emissions trading system (EU ETS) is used by industries to emit greenhouse gases in the EU at the lowest cost. In this system, industries buy and trade emission credits, with the idea that the cap on emissions will be steadily reduced, over time (European Commission, 2019-2). Since its inception, sectors with large, traditional emitters of greenhouse gases can use the ETS system, although this system is under constant development.

In the 1990s, Chinese leaders viewed the harm to the environment caused by industrialisation as '...a necessary price to pay to alleviate large-scale poverty.' (Li, 2016). Nevertheless, China has engaged in bilateral agreements with countries such as Germany and the United States, to prevent climate change.

The differences between regions and the changes in sectoral structure of the economy are very important for China and a reason for using 'carbon intensity' as an indicator of greenhouse gas emissions. This indicator is calculated by relating greenhouse gas emissions to GDP or to the value added of an industry. Thus, it is an indicator of the emission efficiency of production processes. As the services sector grows and the manufacturing industry develops products with more added value, the emissions per unit of GDP go down.

In 2020, China announced its intentions to become climate-neutral by 2060. The European Union aspires to achieve this by 2050. It is unclear what the Chinese ambitions for 2060 will mean for carbon intensity as a central indicator of Chinese climate policy. The CCICED Special Policy Study on this subject explicitly argues in favour of an absolute target ('emissions cap'), as this would provide much more certainty (CCICED, 2021-2).

6.5 Case: Port of Rotterdam — Towards a Circular Economy Port

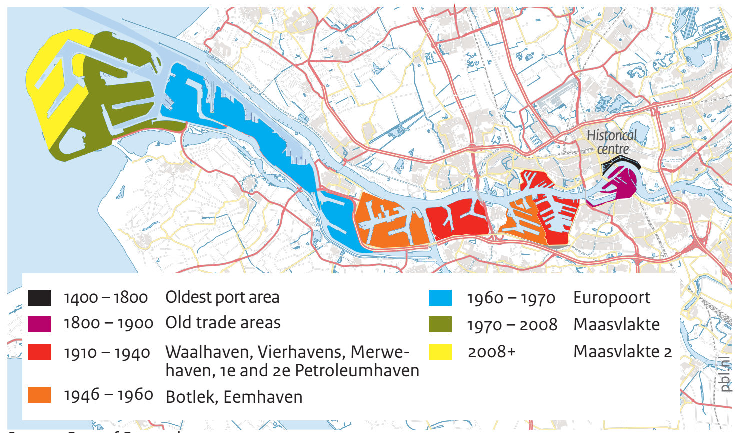
The Port of Rotterdam is aiming to move towards renewable energy use and decarbonisation of its activities, by 2050. The transition of ports towards a sustainable economy is important to the future of maintaining global trade and growth in the traditionally unsustainable domain of shipping, handling of raw materials (especially materials such as crude oil) and energy production.

In the early 1960s, Rotterdam became the oil port of Europe, making it the biggest port in Europe and solidifying the Rhine as an essential trading route in Europe, in both the 20th and 21st century.

In the late 1960s, cargo shipments by container began in the Rhine. Consequently, inland container ports along the Rhine were established, as well (i.e. in Mannheim). The Ports of Rotterdam and Antwerp comprise about 95% of barge container transport to and from the European seaports (Notteboom, 2017).

At the end of the 19th century, the port began to expand on the south bank. Over the course of the 20th century, the port expanded further and further westward, away from the city centre, towards the North Sea, to be able to handle larger cargoes. In the 1970s, new port expansions began on reclaimed land in the North Sea and continue today at Maasvlakte 2 (Figure 44). The ports from the 19th century and older are no longer in use, today, and have been transformed into urban areas. Maasvlakte 2, for the time being, is the last port expansion planned. Any new port activities must take place within the existing port area.

Figure 44
Port of Rotterdam development



Source: Port of Rotterdam

The Port of Rotterdam was originally located in the centre of the city. During the port's expansions and to keep up with the increase in scale in shipping, the new ports were built further away from the city and closer to the sea. Most of the old port sites are no longer used as such.

Circular port economy
Ports are important for the future circular economy because of their position as export-import hubs of raw material and energy users (e.g. Port of Rotterdam). Additionally, they are often located near industrial cities, and circular economy projects offer new economic opportunities for the areas (Gravagnuolo et al., 2019). These projects encounter the seemingly contradictory ambitions of economic goals and growth on the one hand, and sustainable development on the other. Rotterdam attempts to overcome this contradiction by becoming circular with regard to plastic, rubber, biomass, metal, mineral, chemical and industrial waste. Some existing infrastructure is suitable to be adapted to

renewable resources (e.g. some coal-fired power plants can also burn biomass), but this is more complicated for other fossil-fuel intensive infrastructure (e.g. refineries and the industrial cluster). Furthermore, the Port of Rotterdam plans to install CCS and CCU and the related infrastructure to transport the residual heat, for example to greenhouses, homes and offices. Some greenhouses are already connected to carbon dioxide pipelines from the port, improving growing conditions for plants.

This type of transition technology also poses a problem, as it leaves very little land for the development of the Port of Rotterdam. One solution to this problem has been to divert non-essential business back to the inner city, thus leaving space for industrial activity at the port.

In 2015 and 2016, two new coal-fired power plants were installed at the Port of Rotterdam. These are 'clean coal' installations in which flue gas treatment technology mitigates the air polluting effects of burning fossil fuel. So far, the originally intended installation of CCS infrastructure has not been realised. By 2030, the plants will no longer be allowed to burn coal. This means that, despite the claimed carbon efficiency of newer plants, they will need to be phased out or converted into biomass-fired plants. Such proposed solutions demonstrate the ongoing efforts to retrofit existing unsustainable forms of energy production to allow the use of renewables. Carbon pricing may force the port to transition more rapidly towards a fossil-free economy, as it would make the use of fossil fuels more expensive than the renewable alternatives and their infrastructure.

The sustainable transition is also essential for the image of the Port of Rotterdam. Like the previously polluted industrial Emscher Landscape Park in Germany, a social and economic transition of the currently fossil-fuel-heavy port is essential for the development and social acceptance of the port and the attractivity of the region. Thus, a holistic approach to revitalise the port may ensure the longevity of sustainable investments and the economic functioning of an area.

In terms of hinterland connection, the Port of Rotterdam is focused on facilitating different modes of transportation to allow for the most efficient and sustainable transport of goods to the hinterland. For example, the use of freight trains and inland navigation instead of lorries to transport materials and goods. For inland navigation, battery technologies for vessels are being tested, which require cooperation with inland terminals. This initiative is especially important since the bunker fuel that is currently used by these vessels is an important contributor to the port's carbon footprint and local air pollution. A railway line dedicated to freight trains to the German border was constructed in the 1990s. The line currently operates within the Netherlands only and is still waiting for improved connections to the German railway system.

6.6 Case: Green Initiatives at the Port of Shanghai — Shore power

The Port of Shanghai has its first experiences with implementing shore power. The use of shore power instead of a ship's own auxiliary engine contributes to the greening of the port, by reducing harmful emissions (SO_2 and NO_x) and — if that power is generated in a renewable way — also reduces greenhouse gas emissions.

In 2016, the Port of Shanghai was the world's busiest container port, with handling over 37 million TEUs (i.e. twenty-foot containers). The port stretches over 3 zones: the Huangpu river, the Yangtze River and the Yangshan Deep-Water Port (opened in 2005). Shanghai is an important trade hub and is critical for the economic activities along the Yangtze and into the hinterland.

Shanghai implemented a three-year action plan for green ports (2015–2017) to promote the construction of the green port and launch the idea of shore power.

Docked ships use a large amount of bunker fuel and diesel to meet their huge electricity demand. By using shore power, ships can turn off their auxiliary engines and use the electricity provided by the port to power the main shipboard system. This is a more environmentally friendly way of supplying energy to ships. Over the space of 24 hours, a medium-sized container ship is estimated to emit an amount of $PM_{2.5}$ pollutants during its stay at the port that is equivalent to the emissions from 500,000 heavy trucks. At present, the Port of Shanghai handles about 42,000 vessels with international destinations, per year. The pollutants that these ships emit to the city's atmosphere mainly consist of sulphur dioxide and nitrogen oxides. This includes a particularly large amount of emissions from sea-going vessels. Using shore power instead of auxiliary engines will reduce the emission of diesel particulate matter, nitrogen oxides and sulphur dioxide by up to 95%.

By the end of 2017, the Port of Shanghai installed 9 sets of shore power equipment, 2 at the Guandong Terminal, 3 at Yangshan Phase IV, 2 at the International Cruise Terminal, and 2 at the Wusongkou Cruise Terminal.

Challenges remain to see a green transition in the Port of Shanghai. For one, construction costs highly depend on national and local subsidies. The construction cost of shore power facilities in cruise ports is about CNY 50 million per set, while, in container ports, this is about CNY 25 million per set. The corresponding facilities onboard the vessels also need to be transformed for docking. For instance, the Fuqiang China, investment in the world's first large bulk carrier equipped with shore power equipment has a 10-year cost-recovery period. Furthermore, current laws and regulations do not include the mandatory use of shore power by ships, which means there is no incentive for shipping companies to implement it as long as obvious economic interests are absent.

6.7 Findings on decarbonisation in river basins

Climate change mitigation requires a significant reduction in greenhouse gas emissions, amongst other things. For China, the decarbonisation challenge comes just after and overlaps with the more traditional environmental challenges. This is in contrast with the countries along the Rhine, where pollution reduction started earlier and, currently, in the 2020s, the focus is predominantly on reducing greenhouse gas emissions. As the cases illustrate, port cities are strategic locations for the decarbonisation challenge, as they connect industry and infrastructure with the hinterland. Moreover, port cities have a strong influence because of their size, economy and knowledge about logistics, industry and raw materials from both the region and the hinterland.

7

Observations on the interplay between environmental and spatial policies in the Yangtze and Rhine river basins and further steps

长江及莱茵河流域环境与空间发展政策对比观察及未来策略

This comparative study describes the development of urbanisation, environmental pollution and efforts to decarbonise and implement climate adaptation infrastructure in the Rhine and Yangtze river basins between 1950 and 2022, and offers projections to 2050.

In general, for both river basins urban, agricultural and industrial development evolved in the 19th and 20th century with little regard for the resulting pollution of the surrounding environment. However, the negative effects of pollution and major polluting incidents brought attention to the environmental and economic importance of preserving the river basin's biodiversity and environmental quality.

Although river ecology had already been identified, as early as in the 19th century, it was not until the 1970s to 1990s that environmental awareness in the Rhine river basin and western Europe more generally, became more widespread, with the occurrence of environmental disasters and very low water quality as a result of decades of industrial development. Both the European Union and individual countries began drafting agreements and developing technologies to limit pollution and preserve water quality for drinking, agriculture, recreation and even certain industrial uses. Incidentally, this period coincided with western Europe's transition towards a post-industrial and service-oriented economy.

China's industrialisation occurred more recently, and, from the start, was accompanied by environmental regulations, at the same time that these were also being implemented in western Europe. In the 1970s, 1980s and 1990s, China's economic transformation led to an increase in pollution and carbon emissions. This transformation relied largely on heavy industry and manufacturing enabled by coal. The consequence of this rapid and transformative economic period was pollution and decreasing air quality. The Yangtze river corridor was both a key recipient and producer of this pollution, being one of China's most important economic corridors, connecting the Port of Shanghai to the Chinese hinterland. However, by the 21st century, the need for diversification of energy sources, reduction in air pollution, and the pressure on China to decarbonise grew both domestically and internationally, and the country started to make large-scale investments in renewable energy sources, such as hydropower (i.e. Three Gorges Dam), wind and solar power. Thus, in China, the development of environmental policy and renewable technologies occurred together with continuing and even increasing emissions levels.

China and Europe face major sustainability challenges, which often also have a specific spatial embedding at the scale of a river basin. This requires a long-term vision in which spatial interventions can be combined with ecological measures at an appropriate time. These spatial and ecological interventions not only reinforce each other but can also at least mitigate each other's disadvantages.

If we try to combine the strategies of urbanisation, decarbonisation, climate adaptation, the restoration of biodiversity and pollution control, several preconditions and considerations come to the fore. The following sections discuss these matters in more detail, based on the spatial perspective, trade-offs, and time dimension.

7.1 Observations: A spatial approach enables combined strategies in environmental planning

The case of Germany's Emscher Landscape Park is exemplary for an integrated spatial approach. It shows the risks of employment being dependent on mining. The efforts to create a more diverse labour market, in combination with revitalising the physical environment by restoring rivers to their natural state and cleaning them, are bearing fruit. In addition, much of the industrial heritage has been made publicly accessible and new icons have been built in the landscape. This strengthened the area's identity and also attracted recreational users, partly thanks to the restored nature.

Emscher Landscape Park is not the only example that clearly shows how a combined approach to the challenges posed by the environment and spatial planning is much more effective. There are numerous examples of integrated approaches. Greenhouse gas emissions often go hand in hand with the emission of environmental pollutants, which is why decarbonisation and the reduction in environmental pollution can often be tackled together. And there can be a relationship between climate adaptation and biodiversity restoration — for example, restoring riverbanks to their natural state also mitigates the risk of flooding and restores the habitats of plants and animals.

Policy approaches have tended to be more 'holistically' minded, such as the Rhine 2040 project from ICPR and the Water Frameworks Directive that focuses on the whole river basin rather than only the area within national borders. The Room for the River project in the Netherlands provides room for floodwaters to expand naturally, instead of trying to contain the excess water. The project, although costly, protects against flooding while also including other objectives, such as those related to housing, nature and recreation.

In China, the Yangtze River Protection Law prioritises ecological well-being and the protection of the holistic integrity of the Yangtze environment over economic and social ventures on the riverbanks. However, there are large economic, cultural and geological differences between Chinese regions. This calls for a regional approach in the implementation of green development.

It has also become clear that the sustainability objective for a catchment area may also need to consider displacement issues. Where will solar panels and wind turbines be placed and will this not be at the expense of landscape views, recreation, peacefulness, food production or biodiversity? Spatial planning can intervene on many aspects of both the built environment and nature. Such interventions may include building density, building types and functions, location and development size. Urban and landscape planners and designers can create an optimal interplay between these five aspects, over time. Many climate adaptation measures, such as those on heat stress and water retention, in addition to the choice of materials and layout of public spaces, are also related to building density, building type and location. The layout of a city, once it has been built, can only be changed at great expense, and affects numerous aspects of sustainability and liveability, such as mobility, climate adaptation and health.

In China, there are spatial zoning measures that would be unprecedented along the Rhine, such as the ban on new industrial sites within a 5-kilometre radius of a river. In terms of climate adaptation, there are many pilot projects along the Yangtze that would be impossible to implement along the Rhine due to their size and rate of development. This would be a highly interesting subject for a comparative study, in view of the far-reaching changes in Europe and the rest of the world, in the decades to come.

Moreover, competing use of land and resources continues to be a core subject of spatial and environmental planning. Population growth and migration to the cities, where there is a lot of employment, propel urban expansion and correlate with an increase in industrial-style agriculture to feed the urban lifestyle. Thus, it indirectly contributes to the reduction in natural land and ecological diversity. Increases in heads of livestock contribute to land-use competition, because cultivating feedstocks for all these animals requires large amounts of land — all over the planet. Furthermore, riverbanks, which are often rich in biodiversity, are often attractive areas for expanding urbanisation, agriculture, industry and water retention.

In addition, large areas of high-density urbanism are vulnerable to hot micro-climates in urban areas, known as urban heat islands, notably in times of climate change. In extended periods of hot weather, these urban heat islands may push up the local temperature by 10 °C or more above that in the surrounding areas (OECD, 2018). The causes of urban heat islands include the construction materials used in cities (asphalt, concrete, steel and brick). These are often impervious surfaces that are also mostly dark in colour and thus absorb heat. The urban heat island effect is also particularly dangerous to elderly citizens living in cities, as they are more likely to suffer from heat-related health problems. On top of that, the share of elderly people is increasing in the European Union as well as in China.

The effects of urban heat islands can be mitigated by the way cities are designed. For example, street patterns affect wind and shade and greenery delivers cooling. The size of a city also affects the size of the urban heat island — the more extensive the city, the greater the effect. If a city has been developed in a star shape or elongated form, fresh air can easily penetrate the city. Because of their linear form, such cities can also efficiently handle public transport and enable easy access to recreational areas in the surrounding countryside, which is not unimportant to a growing middle class with large recreational needs.

Climate change also leads to higher water temperatures and lower flow rates in both the Rhine and the Yangtze, which puts the amount of cooling water for power plants at risk. In Europe, for reasons of water ecology, the temperature of river water used for cooling purposes is limited to a maximum of 23 °C. If the water temperature rises above this limit, the intake of cooling water must be halted. Power plants on the coast are not restricted in this way, but do need to take sea level rise into account. An alternative would be to cool water in cooling towers, but this is very expensive and very visible in the landscape.

The transition from an industrial to a service economy is accompanied by a reduced demand for space that will also be less location-specific. It is being argued that ICT facilities make it possible to work remotely, reducing the importance of physical proximity. This will reduce the pressure on the city. ICT also enables replacing physical retail locations within cities by web shops. On the other hand, urbanisation is a phenomenon that has been progressing steadily for centuries, and the transition from a fossil to a circular economy has an interest in short cycles, which increases the importance of proximity and, therefore, increases the pressure on cities again. Physical proximity also remains important for the exchange of informal information and inspiration.

Finally, many spatial dependencies within a river basin are specific to flow direction. Water and sludge flow downstream, and so do nutrients and industrial and other pollution. In contrast, oil is transported upstream from seaports to inland areas. Seaports are also the locations from where pipelines go inland. Fishes and macroinvertebrates migrate in both directions, depending on their stage of life. Upstream, from the deltas to the hinterland, is also the direction of controlled urbanisation. In the 1950s and 1960s, the Netherlands started to relocate employment from the Randstad to cities further inland. We see the same movement in China, where for example the economic pressure on the Yangtze Delta is being diverted to cities along the middle course of the river.

7.2 Observations: Trade-offs in sustainability and political sensitivities

A coherent environmental and spatial planning policy is needed not only because environmental and spatial policies can reinforce each other, but also because trade-offs can occur. Certain policies can, for example, have both environmental benefits and ecological disadvantages. This report describes many of the possible trade-offs in relation to dam construction. Scientist criticise the construction of dams, notable the Three Gorges Dam, for reasons of fossil-free energy production, because they severely impact the biodiversity and flood-risk of the area, by destroying natural habitats, cutting migration streams of fish and interrupted the flow of silt along the rivers. Because of the latter, dam construction causes coastal erosion hundreds of kilometres downstream, impacting the environmental, ecological, social and economic well-being of areas in river deltas.

Similar, the dams of the Delta Works in the Netherlands not only protect much of the western part of the country against the North Sea, but also close off inlets replacing brackish water with fresh water from the Rhine and the Meuse . For the farms that lay behind the dams, this has presented many more production opportunities, but for biodiversity, an open connection to the sea and a brackish water environment were lacking. Redressing this in key locations required costly alterations.

In both the Rhine and Yangtze basins, major canalisation projects have increased the economic importance of the rivers, and therefore reduced the growth in road transport, but have also worsened flood risk and degraded the ecosystems of these rivers.

Coastal zones are very attractive areas to be urbanised for economic reasons but these locations are prone to flooding. This flood risk is increasing because of climate change.

Urban densification is a good way of preventing urban sprawl on natural and agricultural land, but it does not prevent the effects of surface sealing and urban heat islands, due to larger shares of built area. Besides that, highly dense urban fabric is not necessarily a popular living environment for all people. That is why densification policy should also be coupled with nature-based solutions and a design that stimulates a good living environment.

The use of fertilizer in agriculture increases food production, but also has consequences that form an enduring problem. This is because nutrients used and produced in agriculture find their way into the Rhine and Yangtze through water and soil run-off and cannot be contained at point sources, as can be done for other types of pollution, such as urban and industrial waste water. Even if nutrient sedimentation could be halted today, the nutrients already present in the soil would continue to seep into the water system for decades to come.

With respect to investments in renewable energy sources and infrastructure, novel technologies often require significant upfront land acquisition, economic investments and spatial arrangements. In addition, the novelty of many of these technologies can generate political unpopularity due to their perceived or real risks amongst affected populations. For instance, nuclear power brings risk of disaster and the political backlash of burying the waste near populated areas. There is similar opposition to carbon capture and storage, where many populations are not willing to accept storage of carbon dioxide under or around their areas of residence. Furthermore, biomass is an important resource for the future of energy production, especially in the near term. However, the sustainability of mostly woody biomass is heavily disputed by some interest groups that have a different perspective on sustainability, mainly because of worries about biodiversity and air quality. Therefore, aside from the financial and technical challenges of developing renewable technologies, governments often must reckon with the political reality of their citizens being critical about novel renewable energy sources and technologies. Perception is an important factor on its own.

With many technological developments, there is a chance of trade-offs in the form of rebound effects. For example, while faster connections lead to shorter travel times, they also make it possible to cover greater distances within a given time budget. And the availability of renewable energy from solar panels may not be an incentive for individuals to use energy more sparingly while fossil energy is still being generated elsewhere.

When simultaneously addressing multiple issues, certain synergies often occur, such as in additional benefits, reduced overall cost or increased public support. However, these synergies typically work only to a certain degree. For example, although replacing motor vehicles with combustion engines with electric vehicles will eliminate exhaust emissions of nitrogen oxides and carbon dioxide, about half of the emission of particulate matter remains and will increase with the future growth in traffic.

The balance between reducing consumption and/or engaging new technologies to achieve sustainability remains crucial but tricky in policy decision-making. For instance, technical options, such as carbon capture, utilisation and storage, do not lead to a reduction in fossil fuel consumption and form no incentive for energy technological innovation and energy savings. At the same time, reducing resource-intensive consumption proves to be an unpopular option for many citizens and politicians alike. However, model studies consistently show that both are needed to reach the sustainability goals for the future. The questions that require future exploration, using the input from case studies on these two dynamic river basins, is where and under what circumstances have these types of action been successfully and concurrently pursued and whether there is evidence of these lines of action reinforcing each other?

These trade-offs can partly be mitigated through a spatial, integrated approach, although they will remain politically sensitive. Political sensitivities become more complicated if they are transnational. Sustainable solutions require a collaborative governance component because administrative borders play an important role in river governance and spatial planning and can lead to awkward spatial patterns in border regions, named borderscapes (Harbers, 2003). This is important when thinking about river basins because countries sometimes compete for fresh water at the border, where an upstream country uses a large part of the fresh river water for irrigation, leaving not enough fresh water for the downstream country. In the Rhine basin, the borders also play a role in the layout of infrastructure (De Vries et al., 2007) for reasons of economic competition. In China borderscapes occur along provincial borders, where industrial plants are located close to the border with the neighbouring province. This indicates a lack of interprovincial governance. China tried to address this problem in 2012 by enshrining the principle of Ecological Civilization in its constitution. This principle promotes people living in harmony with nature. However, even in this context it is difficult to create a binding legal framework around such principles without leaving room for regional particularities. This is the final problem with integrated policy planning, as it is essential to the overall well-being of river basins as well as being difficult to roll out. The fact that multiple government bodies are working on the same issue, which make streamlined, efficient solutions difficult to find.

7.3 Observations: Timing for the future

The Delta Programme in the Netherlands shows how, using a vision with a long time horizon, necessary climate adaptation interventions in the landscape can be addressed in phases by allowing them to go hand in hand with already planned maintenance and other activities and, from a budgetary point of view, can be combined with nature restoration, recreation and urbanisation.

This report and the planned general follow-up study can help to identify such crucial points in space and time, on which the necessary interventions for a sustainable river basin can be built.

Now that most environmental quality issues along the Rhine are reasonably under control, the countries along this river are starting to tackle the greenhouse effect. Along the Yangtze, the decarbonisation challenge and the environmental challenge are both on the agenda, while the area is also experiencing rapid urbanisation. And all this at a time when the impact of climate change is becoming ever greater. This study has highlighted cases of sizeable investment in renewable energy sources at an early stage of the transition away from fossil fuel use. Likewise, while still heavily reliant on coal, China has the largest capacity of solar, wind and hydropower in the world, through large-scale state-led investments into renewable energy.

For policy-making on the sustainability of river basins, one should actually be able to look into the future to see whether it makes sense to invest in a certain type of technology or infrastructure. In terms of technology and lifestyle, the future is uncertain. Of course, promising sustainable technologies are emerging, but whether they will be adopted remains to be seen. Social acceptance also plays a role, here. Without a well-founded scenario, it is therefore difficult to invest in, for example, infrastructure that supports sustainable development. On the other hand, investments can also force a breakthrough for a certain type of infrastructure.

The crucial questions about the time dimension, therefore, concern which investments will be no-regret, which are linked to international treaties and from that point of view are a mandatory effort, which elements of infrastructure will be written off and when (early, or not at all), and which trends are expected to continue.

For dossiers on which there is no policy yet, thorough preparation is crucial, so that if there is a political opportunity, action can be taken immediately. A few examples from the past illustrate that disasters can work as a catalyst for policy. In the Rhine basin, in 1986, the ecological disaster caused by the fire in the Sandoz chemical complex near Basel accelerated international agreements on river pollution and water management. And in the Netherlands, flooding events in 1993 and 1995 led to the Delta Programme being established. It is important to note that, in both cases, these plans had already been largely prepared, but needed momentum to gain political support. The fact that disaster works as a wake-up call is usually a political reality. In any case, it is advisable for experts to be prepared for such disasters and for proper monitoring to be set up, in advance.

The longevity of the solutions and of old patterns is important when considering new infrastructure and interventions in river basins. Urban infrastructure (such as street networks), industrial installations and river dams carry very high investment costs. This is one reason why the results of investments tend to be very long-lived (and early write-offs correspondingly painful). In addition, it is difficult to phase out heavy and expensive mega-infrastructure because it usually is incrementally improved and repaired. This means that, once built, urban areas or infrastructure create preconditions for everyday life, for decades or even centuries, also in terms of sustainability, and can only be restructured at extremely high costs.

Planning for 2050 and beyond means breaking the established way of creating single-issue infrastructure by, instead, creating basin-minded projects. But early termination of these large infrastructures can be very costly. For instance, the newly built coal-fired power plants in the Port of Rotterdam are not in line with the sustainability goals of the Netherlands and will have a very short period of use, relative to their construction costs. At the same time, similarly long-term investments can steer future sustainable developments. For instance, investments in infrastructure that generates and transports hydrogen and carbon dioxide are imminent and might be ‘game changers’.

Along both the Yangtze and the Rhine, there are many experiments concerning the restoration of biodiversity, climate adaptation, decarbonisation and pollution control. For the near future and beyond, the two river basins can learn from each other’s experiences.

7.4 This report as a prelude to an in-depth study on the river basins

This report investigates the relevance and scope of a broader study comparing the Rhine and Yangtze basins for environmental and spatial planning challenges.

Mapping the locations that are related to biodiversity, environmental pollution, urbanisation, climate adaptation and decarbonisation makes it easier to spatially relate them to each other and to describe their interplay. Understanding this interplay helps finding holistic concepts to combine challenges. Comparisons with other river basins serves as a mirror, to recognise peculiarities, to put them in perspective, and to learn from each other.

Europe and China are facing the same sustainability challenges, but differ with respect to the phases of economic development in which they manifest themselves. Instead of reactive policies, solutions require an overall vision for 2050 and beyond, so that the associated investments can be spread out and matched to projects that are needed anyway. This report argues that a spatial approach to environmental problems is relevant and that much knowledge can be exchanged between river basins. This not only concerns knowledge about governance on a transnational scale, but also on a local scale. The follow-up study should include more and more in-depth case studies at micro level, especially for the regions of the Port of Rotterdam and Port of Shanghai.

In essence, the successive phases of environment and spatial policy described here are reactive. However, an anticipated new situation (due to climate change, economic, social and spatial changes) could be taken as the starting point for future policy. To consider how this could work, for example, in the Yangtze or Rhine basin.

Also, more parties should be involved in a follow-up study, both in the Yangtze and Rhine catchment areas. Parties with knowledge on, for example, energy, industry, urbanisation, biodiversity, agriculture and the related governance are indispensable for both river basins.

The comparative study could eventually be extended to one or two other river basins, for example, that of the Mississippi river, which faces similar challenges as those of the Yangtze and the Rhine, but differs with respect to governance.

7.5 Focus questions

In general terms, questions identified in this study can be more specifically addressed in the follow-up study.

- How to balance the spatial challenge of competing functions, such as urbanism, agriculture, energy production (sustainable energy production) versus ecological and river basin 'health'. How to deal with the trade-offs of biomass, carbon capture and dams? What role can design play?
- How can the ports with their associated petrochemical complexes play an important role in making the river basin sustainable?
- Can we identify key moments and locations for interventions? Where is investment needed in the future and which of the infrastructure is redundant or can be written off?

More specifically, assuming that any future in-depth comparison will be placed in the framework of a CCICED policy study on truly integrated approaches for managing river basins in the next decades, it would make sense to structure it along a handful of axes of integration between environment and spatial policies, as follows. Each of these would tease out strategic lessons about when to intervene, and what frame to apply.

1. Climate change and resilient development
   - What are the experiences and measures to cope with climate change and enhance resilient security in densely populated urban areas?
   - What are the experiences in the planning and construction of green ecological infrastructure, considering fast-changing economic and social contexts at the scale of urban agglomerations?
2. River basin pollution management and industrial decarbonisation development
   - What are the measures that control pollution in river basins, especially across jurisdictions?
   - What are the development paths of industrial transformation and decarbonisation and the experiences of government intervention?
3. Shipping organisation, port layout and shoreline utilisation
   - Experiences with planning and implementation of inland and sea shipping and multimodal carbon-efficient transport.
   - Experiences with ongoing urban redevelopment and shoreline restoration of the riverbanks in times of climate change.
4. Regional management and policy coordination
   - Transnational cooperation mechanisms and policies in the Rhine river basin, from 1950 onwards.
   - Cross-provincial cooperation mechanisms, policies and problems faced in the Yangtze river basin, from 2000 onwards.
   - Policy recommendations that are suitable and operable for the Yangtze river basin and elsewhere on the globe.

7.6 Data availability

A prerequisite for comparing two river basins is the availability of data. This report reveals a number of cases where this availability is insufficient.

First of all, river basin delimitations usually do not follow data delimitations. Many physical spatial data sets, such as on land use and emissions, can be aggregated within river basin boundaries, but economic and demographic statistics, for example, are aggregated within administrative areas, which usually do not follow river basin boundaries. Indeed, rivers traditionally often form the boundary of an administrative unit, so the administrative units usually do not include the banks of both sides of the same river.

In second place, not all data sets are available for both catchments. In that case, different data sets have to be used, with the risk of different classifications.

Third, not all data sets are up to date. For a report covering the 1950–2050 period, this is not an insurmountable problem, but broader studies do require up-to-date data sets. If such a broader study would be organised under the CCICED flag, it is easier to have Chinese data at one's disposal, that are not yet publicly available.

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