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Renewal of civil infrastructure. Dutch national forecast for replacement and renovation

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Summary

The civil infrastructure in our country is worth more than EUR 300 billion. This infrastructure is ageing and it is being used by more and heavier vehicles than had been anticipated at the time of construction. How long will our bridges, viaducts, locks, dams and quays last?

The costs of preserving the existing infrastructure will rise sharply in the coming decades. Making a reliable forecast for this is difficult, because there is much we do not know. How many infrastructural and hydraulic structures are there? What is their condition? Are there any hidden defects? How long will they last from a technical point of view? How many gridlocks await us? This goes to show that it is indeed very complicated to predict for how long infrastructural and hydraulic structures, which have a planned service life of between 60 and 120 years, will last after today. For this reason, few asset owners dare to make forecasts about the replacement and renewal of all infrastructural and hydraulic structures under their responsibility. Nevertheless, we need to gain a better understanding of the future of our infrastructure. This will avoid unforeseen costs and disturbances to traffic and shipping.

Despite the many uncertainties, the present study provides, for the first time, a national forecast for the replacement and renewal of the entire civil infrastructure. This is a ‘test’ that the author invites those involved to repeat periodically, each time a little more complete and precise. Figure S.1 shows the result.

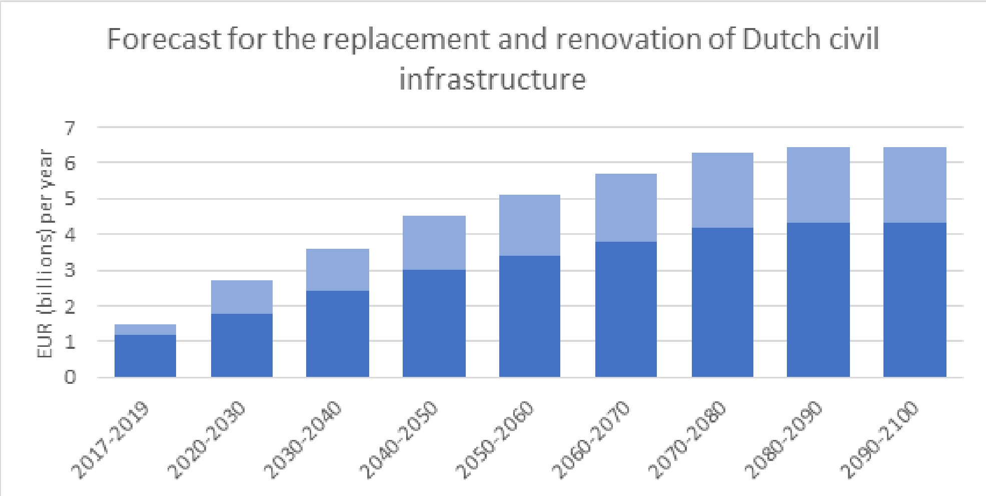

Figure S.1: Forecast of civil infrastructure renewal costs with margin of uncertainty.

Today, we spend over EUR 1 billion a year on civil infrastructure renewal and this amount will gradually rise to EUR 3–4 billion in 2040–2050 and EUR 4–6 billion a year thereafter.[1] The peak in costs will be somewhere around 2080. On top of this, preserving the existing infrastructure will cost around EUR 7 billion a year in management and maintenance.

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[1] Replacement and renewal only, excluding regular maintenance.

This forecast is based on existing forecasts by the Directorate-General for Public Works and Water Management (Rijkswaterstaat, RWS) until 2050, by the joint provinces until 2060 and by the municipality of Amsterdam for bridges and quays. The present study adds a new forecast for the renewal costs of all infrastructural and hydraulic structures in the next hundred years. The result from Figure S.1 is an extrapolation of these four forecasts to the whole of the civil infrastructure. The time horizon is the end of the century.

It is not only money that is needed to tackle the replacement challenge. The author offers four key recommendations for an effective and efficient approach:

- Produce national forecasts periodically in which the currently large uncertainties are gradually reduced.
- Professionalise asset management at the area level and make arrangements for achieving this, for example by setting up a central organisational unit for each asset owner or for groups of small asset owners.
- Put asset management at a greater distance from politics in order to enable continuity in budgets and planning. Leave supervision of the frameworks and the quality-budget balance to the politicians.
- Improve the cooperation between asset owners, exchange knowledge and experience and set up programmes for knowledge development and innovation together.

Inhoudsopgave

1 Introduction

The Netherlands has 85,000 bridges and viaducts, 83,000 culverts and 2,400 km of quays, while 7,800 pumping stations ensure dry feet. Our country has a lot of waterways and roads and therefore also many infrastructural and hydraulic structures where water and roads intersect. All civil infrastructure combined is worth more than EUR 300 billion. This is by far the largest public asset and exceeds the total public debt (section 2).

However, our civil infrastructure is ageing. Much of it was built from the 1960s onwards to coincide with the rise of car traffic. Quite a few structures are even older. In addition to ageing, the load on the structures is greater than was calculated at the time. The strong growth of freight traffic in both number and weight was not foreseen. Another factor is that waves have grown higher due to climate change. An important question is how long our infrastructure can last without renewal or replacement.

Earlier studies show that the costs of preserving the existing infrastructure will rise and that there will be a peak in renewal costs (section 3). However, these earlier studies do not provide a picture of what is ahead of us nationwide. For this reason, the Core Coalition for Bridges and Locks[2] of Bouwagenda (task force Construction) has taken the initiative to commission an ‘example’ of a national forecast. The result, which lies before you, contains figures that illustrate the renewal challenge until the end of this century. These figures are based on the first-ever comprehensive overview of the total number of infrastructural and hydraulic structures in the Netherlands, divided into main types.[3] Based on information on the year of construction and assumptions on the technical service life, the author has made a forecast for the increasing replacement costs of these infrastructural and hydraulic structures (section 4).

The national forecast for the challenge to replace the civil infrastructure is an extrapolation of the four available forecasts, each for part of the infrastructural and hydraulic structures (section 5). The result is no more than a rough estimate.

Currently, the replacement challenge is not sufficiently on the political and societal agenda. Reasons for this are lack of knowledge, lack of political priority for the existing infrastructure and highly fragmented ownership (section 6). Four major improvements in infrastructure ownership are required to manage the replacement challenge (section 7). It goes without saying that the renewal should be circular, climate-neutral and sustainable (section 8).

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[2] Membership as of summer 2020: Koene Talsma (Bouwagenda task force), Anita Baas (RWS), Marco Hofman (Bouwcampus), Marten Klein (municipality of Amsterdam), Lindy Molenkamp (province of North Holland) and Arie Bleijenberg (TNO).

[3] See Bloksma and Westenberg, 2021, compiled at the request of and co-funded by Bouwagenda.

2 Over EUR 300 billion

The value of all civil infrastructure in the Netherlands has been estimated at EUR 318 billion.[4] This includes roads, railways, dykes, waterways, sewerage and all associated infrastructural and hydraulic structures, such as bridges, tunnels, locks and dams.

This civil infrastructure is almost entirely owned and managed by government bodies – municipalities, provinces, water boards, RWS and ProRail – and semi-public bodies, especially Amsterdam Airport Schiphol and the ports. This value of EUR 300 billion represents by far the largest public asset, as shown by the Dutch government balance sheet (Table 1). The value of the civil infrastructure is greater than the total financial debt of all government bodies (before the coronavirus pandemic).

Government balance sheet for 2018	EUR (billions)
Non-financial assets	**490**
Civil infrastructure owned by government bodies	283
Civil infrastructure owned by semi-public bodies	35
Buildings	90
Land	37
Oil and gas reserves	19
Other	58
Financial debt (liabilities minus assets)	**-300**
Capital balance	**225**

Table 1: Government balance sheet for 2018 (Source: CBS National Accounts; own adaptation in Appendix A).

This sizeable public asset requires careful ownership. Preserving the functions of the existing infrastructure requires maintenance and, at the end of a structure's service life, renewal or replacement. An average technical service life of 80 years amounts to annual renewal costs of EUR 4 billion *on average*. By contrast, current renewal expenditure is between EUR 1.2 and 1.5 billion[5], well below the multi-year average of EUR 4 billion.
Another EUR 7 billion is needed each year for management and maintenance.[6] On the basis of these rough figures, the preservation costs amount to EUR 11 billion *on average* per year. Currently, an estimated EUR 8 billion per year is spent on preservation.[7]

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4 Based on CBS figures. See Appendix A.
5 EIB estimate from 2020.
6 Annual maintenance costs of 2.1% of the infrastructure's replacement value (based on Bloksma and Westenberg, 2021, and in line with EIB, 2020).
7 EIB estimate from 2020.

These rough figures confirm the expectation that preservation costs will rise. This increase has two causes. Firstly, delays may have occurred in regular maintenance and in timely renewal. Secondly, a peak in replacement costs is imminent due to an earlier peak in new construction. In the case of transport infrastructure, there was a construction peak between 1960 and 1980, so there will be a peak in renewal costs some 80 years later. In the following sections, the author estimates when the peak will occur and how high it will be.

3 Three forecasts

Three asset owners have issued long-term forecasts for preservation costs: the joint provinces, Rijkswaterstaat and the municipality of Amsterdam. These forecasts provide a first glimpse into the extent of cost increases and when they can be expected.

Provinces
At the behest of the Association of Provincial Authorities, an estimate was made of the 'financial costs of the preservation of provincial infrastructure'.[8] 'Preservation' in this instance covers both management and maintenance as well as replacement and renewal. Table 2 provides an overview of the number and length of the roads, waterways and infrastructural and hydraulic structures owned by the provinces.

Infrastructure	Number/length	Source
Roads	7,817 km	2020, CBS
Waterways	1,487 km	2018, CBS
Bridges and viaducts	2,882	2020, Bloksma Westenberg 2021
Tunnels and subways	667	"
Locks	214	"
Dams	279	"
Pumping stations	52	"
Culverts	5,586	"

Table 2: Infrastructure owned by the provinces.

The estimate of preservation costs is shown in Table 3.[9] The table shows that the management and maintenance costs will remain fairly constant, as is to be expected if not much new infrastructure is added. The expenditure required for replacement and renewal, on the other hand, will increase. In the period from 2030, this will be about EUR 120 million per year more than at present (2015–2020). This is an increase of almost 60%. After 2030, the costs of replacement and renewal will remain at approximately the same higher level.

[8] MuConsult, 2015. The estimate of future preservation costs is based on information supplied by the provinces, supplemented by general data for the purpose of extrapolation. Six of the 12 provinces indicated at the time that they had a clear idea of the replacement challenge, while the others had some or none.
[9] 'Estimate 2', which is the one the researchers considered the most likely.

EUR (millions) per year 2015 price level	2015–2020	2020–2030	2030–2040	2040–2050	2050–2060
Management and maintenance	341	371	380	370	373
Replacement and renewal	212	284	334	327	328
Total preservation costs	553	655	714	697	701

Table 3: Estimate of provincial infrastructure preservation costs (MuConsult, 2015).

Rijkswaterstaat

RWS estimates the costs of replacement and renewal of the existing infrastructure in periodic ‘forecasts’. Figure 2 shows the most recent result. These RWS forecasts also show that the expenditure required for replacement and renewal will increase. Compared to today[10], an additional EUR 400–600 million will be needed each year in the period 2041–2050. RWS uses a bandwidth of 50% in its long-term forecast in order to take into account the considerable uncertainties regarding the technical service life of the existing infrastructure and the costs of renewal and replacement.

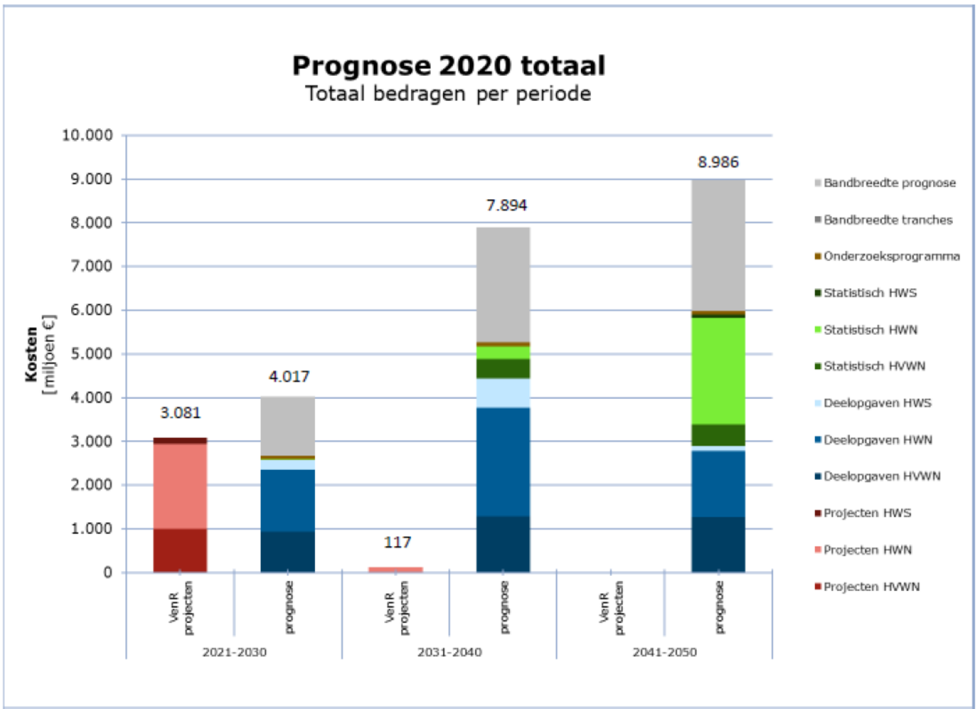

Figure 2: Rijkswaterstaat forecast of costs for replacement and renewal per ten-year period (RWS, 2020).

[10] EUR 200–300 million for replacement in the years 2019 and 2020, according to the Infrastructure Fund and the Delta Fund.

Preserving the existing infrastructure will require regular management and maintenance in addition to replacement and renewal. The latter will require EUR 1.5–1.8 billion each year.[11] In April 2020, there was EUR 1.5 billion in deferred maintenance that is still needed.[12] The total budget requirement for preservation in the period 2022–2035 is EUR 2.6–3.2 billion per year. This is in the order of EUR 1 billion per year more than the currently available budget for RWS.[13]

Infrastructure	Number/length
Roads	7,588 km
Waterways (inland waterways)	3,437 km
Primary flood defences (dykes, dams, dunes)	198 km
Movable bridges	168
Fixed bridges	977
Viaducts	2,894
Tunnels	27
Aqueducts	17
Locks	215
Dams and storm-surge barriers	19
Pumping stations	20
Siphons, culverts	759

Table 4: Infrastructure owned by Rijkswaterstaat (House of Representatives, 2020).

Table 4 gives an overview of the civil infrastructure for which renewal costs have been estimated. RWS (2020) has calculated the replacement value at EUR 58 billion. The estimated replacement costs are therefore 0.3–0.5% of the replacement value, increasing to 1.0–1.5% per year in 2040–2050. An *average* technical service life of 80 years will lead to annual replacement costs of 1.25%. In order to catch up with the long-term average, the replacement costs for RWS after 2050 will probably have to increase in excess of the forecast given for 2040–2050. The peak will not arrive until after 2050.

Amsterdam

The municipality of Amsterdam's Civil Engineering Committee has noted that the management and maintenance of bridges and quay walls have fallen behind schedule.[14] The current rate of replacement and renewal will need to be increased by a factor of 20 in order to have eliminated the backlog in 20 years' time. In response, the Municipal Executive has conceded that the bridges and quays have been neglected. The Municipal Executive has made money and manpower

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[11] PWC|Rebel 2020 for the period 2022–2030.
[12] PWC|Rebel 2020.
[13] Ministry of I&W, 2020e.
[14] Cloo et al, 2019.

available to reduce the backlog.[15] Table 5 gives figures for the civil infrastructure managed by the municipality of Amsterdam.

Infrastructure	Number/length	Source
Road bridges	850	Amsterdam Municipal Executive, 2019
Other bridges	750	"
Masonry quay walls	200 km	"
Other quays and banks	600 km	"
Road tunnels	5	"
Roads	1,792 km	Amsterdam, 2019
Tram and metro	152 km	"

Table 5: Infrastructure owned by the municipality of Amsterdam.

Fragmented picture

The forecasts by the municipality of Amsterdam, Rijkswaterstaat and the provinces confirm the view that renewal costs will rise in the coming decades: for Amsterdam by a factor of 20, for RWS by 3 and for the provinces by 1.6. Together, these three forecasts provide no more than a fragmented picture of the coming renewal challenge. Amsterdam's bridges and quays are not representative of the whole of the Netherlands. Although the forecasts for RWS and the provinces cover all civil infrastructure, they do not provide sufficient insight into the total size and timing of the renewal challenge in the Netherlands.

In order to obtain additional information, an additional forecast was made of the replacement costs of all infrastructural and hydraulic structures in the Netherlands over the next 100 years.

[15] Amsterdam Municipal Executive, 2019.

4 Forecast for the replacement and renewal of infrastructural and hydraulic structures

This forecast was made for infrastructural and hydraulic structures and not for structures such as road surfaces, railway tracks or dykes for two reasons. Firstly, the probability of a peak in the replacement and renewal of civil engineering structures is greater than for other civil infrastructures. This is due to their long service life. An infrastructural and hydraulic structure has a service life of 60–120 years. Road surfaces and railway tracks are renewed more frequently.[16] The second reason for making a forecast for infrastructural and hydraulic structures is that relatively little is known about their number, age and condition. As a result, there is no clear notion of the forthcoming replacement costs either. Bouwagenda took the initiative to produce the first-ever reliable overview of the number of structures per type.

Number/length of infrastructural and hydraulic structures
iASSET and Bureau Westenberg compiled an overview of all infrastructural and hydraulic structures in the Netherlands.[17] The data were derived from the Key Register for Large-Scale Topography. The total number of infrastructural and hydraulic structures adds up to 213,000. This varies from very large structures like the Van Brienenoord Bridge to a small culvert under a country road. Table 6 shows the total number per type, including the estimated replacement value.

Infrastructure	Number/length	Replacement value in EUR (millions)
Movable bridges	8,457	14,226
Fixed bridges, concrete	34,389	19,283
Fixed bridges, steel	10,034	13,538
Fixed bridges, wood	31,693	8,885
Tunnels and subways	3,042	9,119
Culverts	82,642	2,108
Sheet piling	779 km	2,961
Locks	2,011	239
Pumping stations	7,792	448
Quays and jetties	2,423 km	1,939
Dams	33,154	249
Overpasses	182	55
Total		**73,049**

[16] Road and rail foundations have a technical service life similar to that of infrastructural and hydraulic structures.
[17] Bloksma and Westenberg, 2020.

Table 6: Number/length and replacement value of infrastructural and hydraulic structures in the Netherlands (Bloksma and Westenberg, 2021; Tables 51 and 52).

The combined replacement value of all infrastructural and hydraulic structures adds up to EUR 73 billion. This is almost a quarter of the value of the total civil infrastructure.

The map of the Netherlands (Figure 3) shows the location of all structures. It is clear that infrastructural and hydraulic structures are not evenly distributed across the country. The geographical distribution is largely a result of population density and the amount of surface water. The difference in the number of infrastructural and hydraulic structures between the provinces of Drenthe and South Holland, for example, is enormous.[18]

[18] The report *Infrastructural and hydraulic structures in the Netherlands* (Bloksma and Westenberg, 2020) contains many more data per type of structure and type of asset owner.

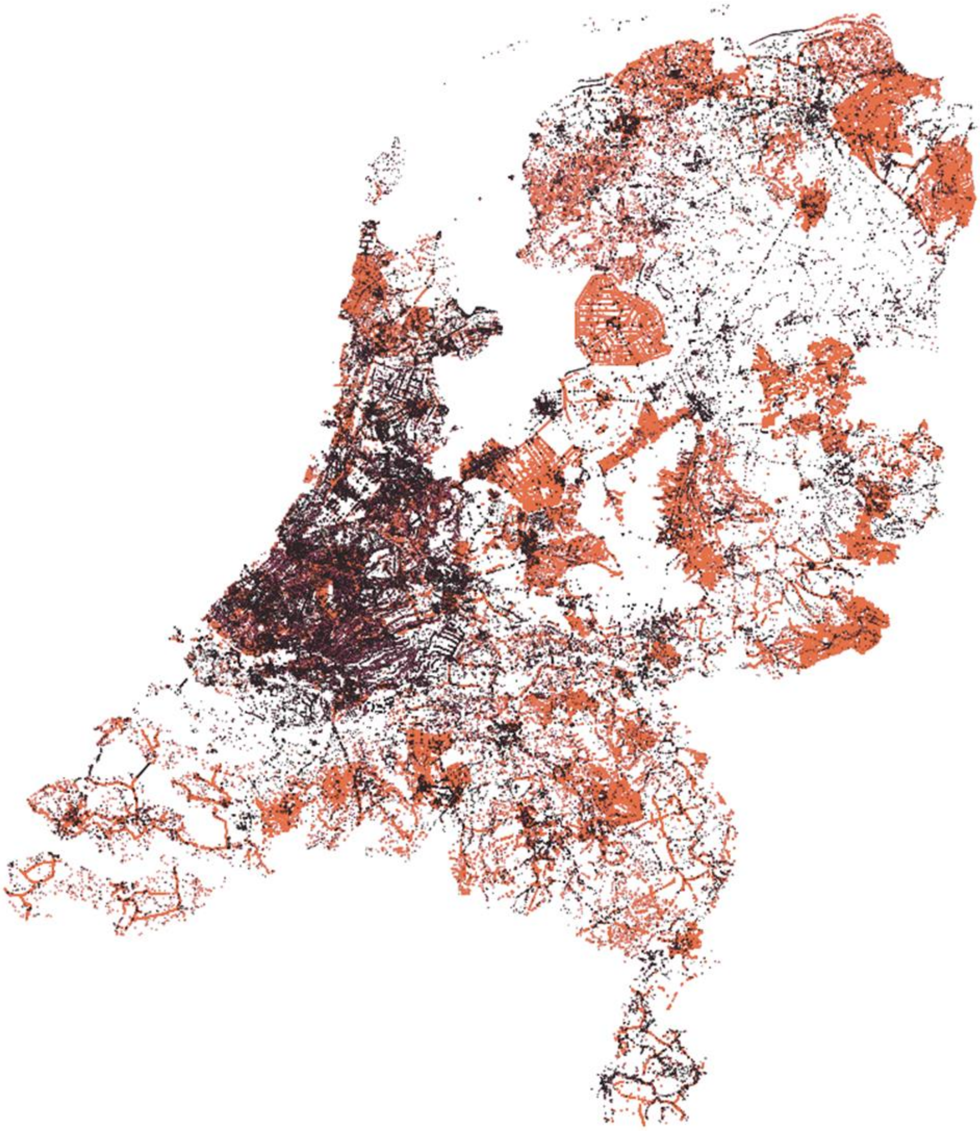

Figure 3: Geographical distribution of infrastructural and hydraulic structures[19] (Bloksma and Westenberg, 2021).

Age

In order to make a forecast for upcoming replacements and renewals on the basis of these geographical data, information about the current age of the structures and their expected technical service life is needed. The Key Register for Large-Scale Topography does not include years of construction. These were taken from the iASSET database for each type of structure and then extrapolated to all structures of that type. This provides an insight into the relative ages of the infrastructural and hydraulic structures. Figures 4 and 5 show the results for the 'dry' and 'wet' structures, respectively. In the case of traffic infrastructure construction, there is a

[19] Bridges, viaducts and large dams and flood defences in black, other infrastructural and hydraulic structures in brown.

clear peak between 1970 and 1980. This is due to the strong growth in road traffic between 1960 and 1980. After that period, the growth in road traffic slowed down, but the importance of good integration increased. More tunnels and complex traffic junctions caused the second construction peak between 2000 and 2010.

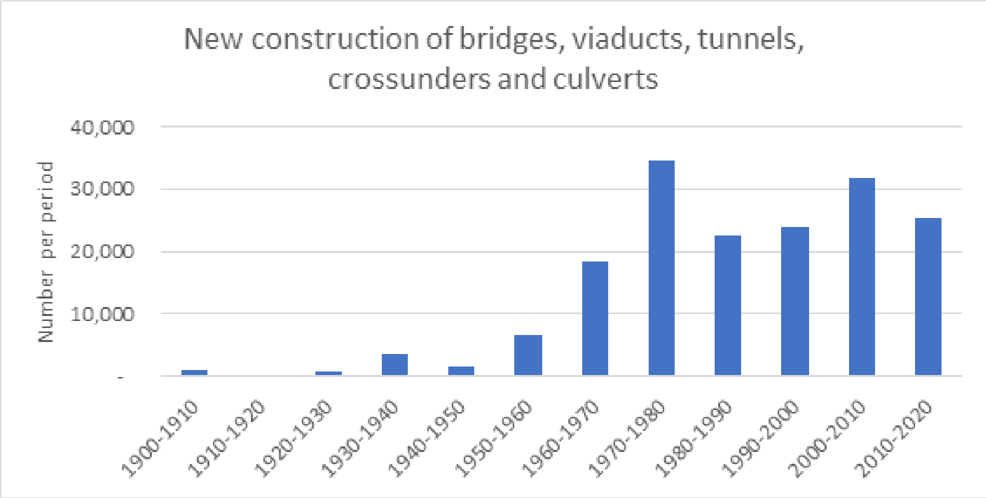

Figure 4: Construction of structures for road and rail traffic (Bloksma and Westenberg, 2021).

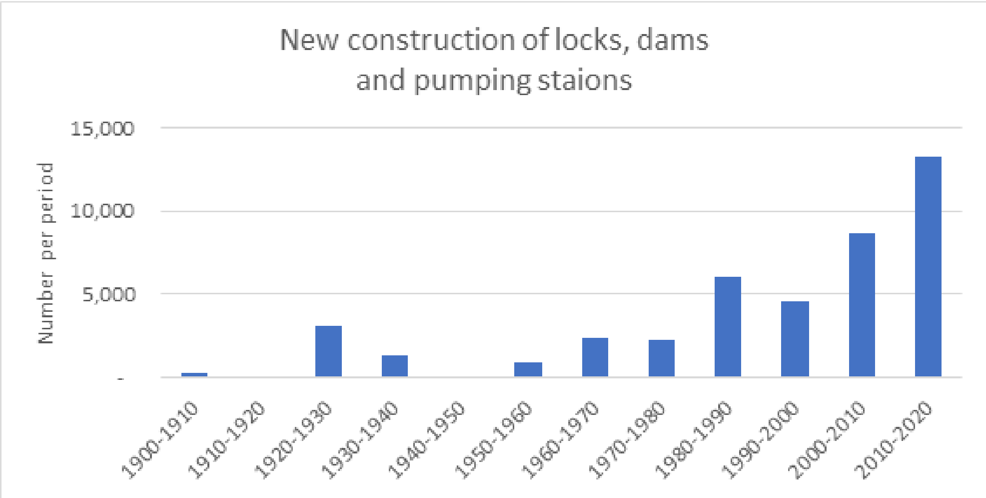

Figure 5: Construction of hydraulic structures (Bloksma and Westenberg, 2021).

Replacement and renewal forecast
Assumptions on the average technical service life were then used to forecast the replacement costs of infrastructural and hydraulic structures.[20] Figure 6 shows the result. A fivefold increase in costs can be expected between now and 2080. This is an increase from EUR 250 million to EUR 1,250 million per year. Apart from confirming that renewal costs will already increase significantly in the short term,

[20] Number/length and replacement value according to Table 6. Assumed technical service lives based on Bloksma and Westenberg, 2021: movable bridges 70 years, fixed concrete bridges 120, fixed steel bridges 80, fixed wood bridges 40, tunnels, subways and culverts 100, sheet piling 60, locks 80, pumping stations, jetties, quays, dams and overpasses 50.

this forecast also shows that it is necessary to look beyond 2050. The peak will not arrive until after that year.

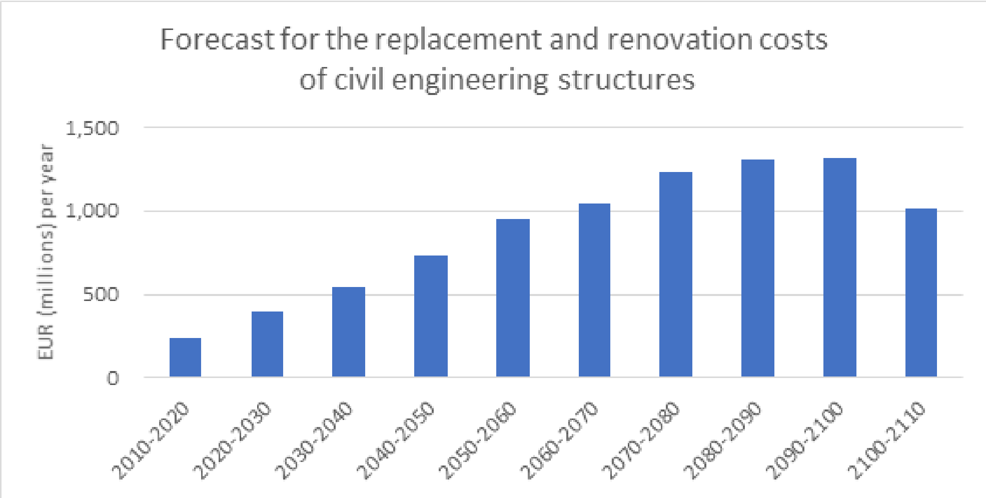

Figure 6: Forecast of infrastructural and hydraulic structure renewal costs.

Comments
The above renewal costs forecast is no more than an indication. There are uncertainties surrounding the figures used for the number/length, age structure, unit costs of replacement and technical service life. The renewal costs of new structures that have yet to be built are not included in the forecast. Additionally, no delays in the renewal of the oldest infrastructural and hydraulic structures were assumed.

5 Forecast renewal of national civil infrastructure

The previous sections provided information on parts of the upcoming replacement challenge. Much is still unknown. Nevertheless, an 'example' of a national forecast for the renewal costs of the total civil infrastructure on the basis of the limited knowledge available follows. This should be seen as an invitation to produce a national forecast every few years that is more precise and better substantiated each time.

Figure 7 shows the national forecast. The costs of replacing and renewing the existing civil infrastructure will rise from over EUR 1 billion a year today[21] to between EUR 4 and 6 billion by the end of the century. The forecast for the period 2040–2050 is EUR 3 to 4 billion per year. These amounts do not include the annual management and maintenance costs of about EUR 7 billion per year.

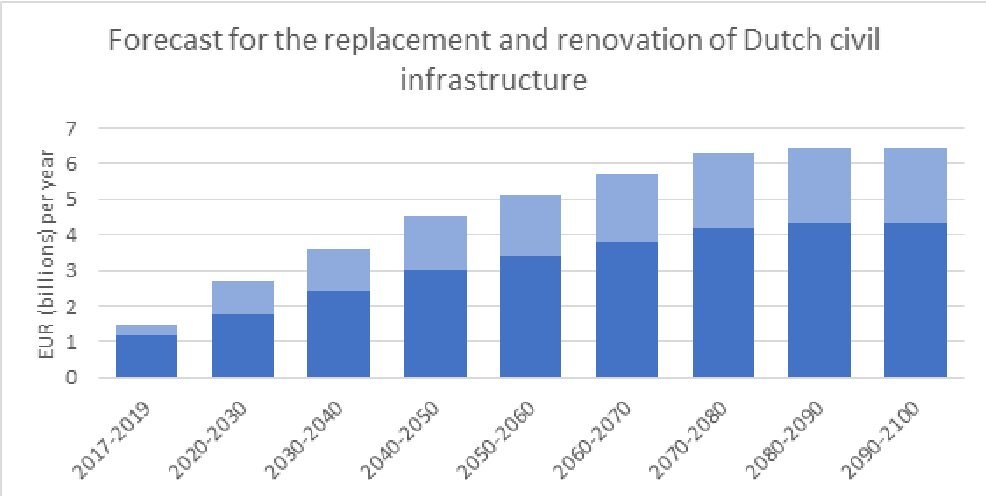

Figure 7: Forecast of civil infrastructure renewal costs with margin of uncertainty.

This test report is an extrapolation of available forecasts for some infrastructural and hydraulic structures to all civil infrastructure, looking ahead to the end of this century. This is based on forecasts from Rijkswaterstaat until 2050, from all provinces until 2060, from the municipality of Amsterdam for its bridges and quays (section 3) and the newly made forecast for the renewal costs of all infrastructural and hydraulic structures in the next hundred years (section 4). The growth factor up to 2050, at 2.5, is slightly lower than the growth factor forecast for RWS and the one for infrastructural and hydraulic structures, which is a factor of 3.0 up to 2050 for both. The reason for this somewhat lower growth in renewal costs is that the replacement of infrastructural and hydraulic structures is more likely to peak than the replacement of road surfacing. This is due to their advanced age. The growth factor in the forecast for provincial infrastructure is only 1.6, probably because roads make up a relatively large part of provincial infrastructure. For the same reason, the

[21] EIB (2020) estimates the replacement costs of civil infrastructure at EUR 1.2 to 1.5 billion per year for the period 2017–2019.

forecast after 2050 uses a growth factor that is almost half that for infrastructural and hydraulic structures. An upward uncertainty margin of 50% has been used, in line with the margin used by Rijkswaterstaat.

The annual renewal costs are EUR 3.0 billion *on average* for the lower forecast and in EUR 4.3 billion for the higher forecast. An average service life of 80 years amounts to *average* renewal costs of EUR 4.0 billion. The amount in the lower forecast is lower and that in the higher forecast a little higher.[22]
The forecasts do not take into account any existing backlogs in replacement and renewal. If there are any, the costs will rise faster.

In the following section, the author discusses the reasons why so little is known about the civil infrastructure replacement challenge.

[22] All these amounts are exclusive of regular management and maintenance.

6 Insufficient priority given to the renewal challenge

It is surprising how little is known about the coming renewal challenge with respect to civil infrastructure. For the first time, we now know with reasonable accuracy how many infrastructural and hydraulic structures there are in the Netherlands and approximately how old they are. However, there is no overview of the technical condition of all these structures. Furthermore, different experts estimate their expected technical service life differently. Experts also differ on the unit costs of newly constructed infrastructure. There is therefore no sufficiently reliable forecast. This is one of the reasons why little political priority is given to the renewal challenge. Only acute safety problems or obstructions receive attention. The unspoken expectation is that things will continue to go well. This lax approach contrasts with the great financial and economic value of the civil infrastructure.

There are three persistent reasons for giving a low priority to infrastructure preservation:
- Lack of knowledge of ageing infrastructure
- Little political priority given to existing infrastructure
- Fragmented infrastructure ownership

These three reasons reinforce each other.

Knowledge of ageing infrastructure
Understanding a 60 or 100-year-old structure is more difficult than designing a new one. This is partially due to a lack of information about ageing structures. Sometimes the drawings and design calculations cannot be found or the quality of the materials used is unknown. Knowledge of degradation factors, such as steel part fatigue and concrete degradation, is still insufficient to make accurate residual life estimates. In practice, ‘new’ degradation factors come to light, such as specific joints in the Merwede Bridge. Furthermore, there is uncertainty about the loads that have acted on the structures over the decades. Have there been any incidents, such as collisions, and how were repairs carried out? How many heavy vehicles cross each bridge per year? All these factors influence the service life of a structure.

Specialists have no choice but to rely on such uncertainties when assessing whether a structure is still safe. Given that safety is paramount, a safe assumption is made for each uncertainty. A combination of safe assumptions results in a very conservative assessment. It regularly happens that due to a lack of knowledge, a structure may seem not to comply with the regulations, while it is in fact safe. To prove this, more knowledge of the structure, materials and loads is needed. New measurement and calculation techniques are being developed to fill such knowledge gaps. This prevents the premature replacement of structures that are no longer adequate only on paper.

With current knowledge, it is not possible to predict the residual life of an entire range of structures. As a result, it is not possible to determine when an individual structure needs to be replaced and, therefore, how much money is required. The increase in the number of unplanned closures is not foreseeable either. This lack of hard figures hampers the generation of sufficient political priority. Conversely, this lack of priority leads to insufficient investment in the sort of knowledge development that would allow more accurate estimates of service lives and failures.

Political priority
The civil infrastructure is largely owned by government bodies. Politicians often give little priority to preserving what is already there. Opening a new bridge has more appeal than preventing an existing bridge from closing. Preserving existing structures is a matter of multiple decades. Many politicians simply do not look that far ahead. Budgets for management and maintenance, and especially reserves for replacements, are often the first to suffer in cost-cutting exercises. This became apparent again after the financial crisis of 2008. Infrastructure preservation is not uppermost in politicians' minds. Asset management is a highly technical specialisation far beyond the understanding of politicians or citizens.

It often takes an accident or incident for priority to be given to preservation. After a 2006 accident involving a flight of quayside steps – one dead and 20 wounded – the municipality of Utrecht decided to replace all quayside steps and to increase the budgets available for the management and maintenance of all infrastructure year on year.
The abrupt closure of the Juliana Bridge in Alphen aan den Rijn was preceded by several worrying recommendations by inspectors, which were only partially heeded. More than a year before the actual closure in 2011, the inspectors recommended that axle load restrictions be introduced immediately. This was not adopted. The bridge was eventually closed after an inspection company had concluded that it was unsafe.[23]
The sudden closure of the Merwede Bridge to heavy traffic in 2016 led to the use of innovative inspection techniques, research into possible degradation of specific joints and the development of a quick scan to re-examine all RWS-managed steel bridges.
The municipality of Amsterdam's extensive Bridges and Locks programme was prompted by, among other things, a critical report by the Amsterdam Court of Audit and the aforementioned audit by the Civil Engineering Committee.

As a consequence of its low political priority, the ownership of infrastructural and hydraulic structures is mainly reactive. Action is taken only after something goes wrong. As a result, insufficient tools and techniques have been developed to predict the safe residual life of infrastructural and hydraulic structures. The lack of such tools makes it difficult to start managing proactively. This completes the vicious circle.

[23] Bijlaard and Ten Heuvelhof, 2012.

Fragmented ownership
There is little technical cooperation between the nearly 400 asset owners of infrastructural and hydraulic structures.[24] Small municipalities rarely have the necessary expertise in-house and lean on external consultants. Sometimes, experts employed by the larger asset owners are called in as troubleshooters. Positive and negative experiences with specific structures or parts are not systematically shared. The existing fragmentation hampers the ability of asset owners to learn more about preserving the existing civil infrastructure.

A joint programme for the development of knowledge and innovations is also lacking. Only a few large asset owners in the Netherlands have the expertise and finances to invest in this.

[24] As of January 2021: 347 municipalities, 21 water boards, 12 provinces, Rijkswaterstaat and ProRail.

7 National replacement and renewal challenge

This ‘example’ of a national forecast for replacement and renewal confirms that the costs of preserving the existing civil infrastructure will rise sharply, from the current level of just over EUR 1 billion per year to EUR 3–4 billion in 2040–2050 and to EUR 4–6 billion per year after that. The value of the existing civil infrastructure exceeds EUR 300 billion and requires a level of care that is appropriate for such an asset. Below are four recommendations for tackling this national challenge.

Periodic national forecast
This ‘example’ is a first step towards a periodic national forecast for replacement and renewal, like the one published by Rijkswaterstaat. The reliability of the estimates will improve over time. Naturally, the forecasts for the upcoming decades will be more accurate than those for the 2050s and beyond.

A sufficiently accurate forecast provides substantiation for amassing the budget required to preserve the existing infrastructure. The multi-year programmes of individual infrastructure asset owners could be brought into line with the national forecast to allow for implementation savings. In addition, the private sector would gain a better insight into the volume of work to be expected, allowing it to adjust capacity accordingly.

Furthermore, periodic national forecasts will provide an insight into the greatest uncertainties and most significant cost items. Targeted knowledge development will lead to reducing the margins of uncertainty and innovations being aimed at lowering the most significant cost items.

Asset management at the area level
Further improvements to asset management are needed to tackle the renewal challenge efficiently. Table 7 summarises the required changes.

Better asset management allows for better timing, which saves money. Replacing or renewing too soon is a form of destruction of capital, but replacing or renewing too late results in unnecessarily high costs due to the urgency and unforeseen disruption to traffic. Moreover, renewing too soon hampers efforts towards achieving circular construction. Timely planning of work actually provides opportunities for the combination of assignments and often leads to a lower contract price.

From	Towards
Incident-driven approach	**Prediction-driven anticipation**
Rules of thumb	**Monitoring of the actual situation**
Individual structure level	**Area level**
Individual databases	**Big data and national overview**
Lack of clarity on backlogs	**Backlogs either absent or known**
Budget-driven	**Political consideration of quality-cost balance**
Temporary project organisations	**Permanent ownership organisation**

Table 7: Overview of changes to asset management.

In addition to accurate timing, the choice between replacement or renewal also matters. This has major implications for service life costs and the environmental impact of the work. This often recurring choice requires a suitable assessment framework. Costs, environmental impact, traffic and the inconvenience of alternatives must be compared systematically. A suitable assessment framework will provide a sound foundation for consistent decisions on replacement or renewal. Currently, this is often done on an ad-hoc basis and with ad-hoc arguments.

To be able to prepare multi-year plans, managers must have an estimate of the technical residual life of all structures in an area. It is possible to obtain sufficient insight into an entire area without the need to measure and assess the many thousands of structures individually. To this end, the insights from detailed analyses must be combined with key figures for the entire area. This will reveal critical types of structures and parts to be examined in more detail. This, in turn, will lead to a greater understanding of the condition of the entire area. Alternating between the individual and area levels is key to maintaining a good grip on the whole challenge. In the realm of civil engineering, this form of asset management at the area level is still in its infancy.

Decisions on preserving existing infrastructure – timing, replacement or renewal – should be prepared by a central unit within the organisation of the relevant infrastructure asset owner. In the current situation, this is often done by a project organisation that is already set up for implementation. The central asset management unit will make considerations at the area level, which will allow it to give direction to project assignments. This central unit will require approval for the assessment framework from those who are politically responsible, thus creating consistency in the approach to the different projects. The asset management unit must be specialised in terms of content. Setting up such a central asset management unit and developing its working methods will take several years.

Asset management at a greater distance from politics
Setting aside funds to meet the costs of preserving the existing infrastructure is part of the regular budget process of the managing government bodies. As a result, there is little certainty about the budgets available in the longer term. In practice,

cutting spending on preservation has proven to be a popular measure in times of austerity. After all, the negative consequences come later. In the long run, the costs exceed the savings realised, because the preservation work is less optimally planned and carried out. Often, preservation budgets only return to the required level after an incident or accident.

Preservation budgets should not be subject to short-term considerations. The beneficial effects of long-term frameworks became apparent, for example, when the duty of care for sewerage was introduced in the 1990s (Spruit, 2021). More calm in the ownership organisation, greater efficiency in operations, fewer incidents and increased continuity for the private sector are important benefits. This will clear the way for politics to focus on the big picture, especially the trade-off between desired quality and available budget. In that situation, political micromanagement of choices for each individual bridge or quay will no longer be necessary.

Joint knowledge and innovation for dry structures
The ownership of civil infrastructure is in the hands of almost 400 different asset owners, mostly municipalities. The CROW technology platform for transport, infrastructure and public space ensures that there are general norms and standards. There are several organisations for consultation and knowledge exchange. These include Road Authorities Meet Road Authorities (Wegbeheerders ontmoeten Wegbeheerders, WoW), CROW, COB, iAMPro, Stadswerk and Bouwcampus. Many asset owners are advised by engineering firms. Naturally, the construction companies themselves also possess plenty of knowledge and experience.

Because of the great importance of structural safety and the technical complexity of assessing existing structures, the reinforcement and bundling of knowledge and experience is desirable. Four suggestions for achieving this:

- Maintaining **a national overview** of the susceptibility to failure, service life, repairs and current degradation of common types of infrastructural and hydraulic structures. This will form a basis for learning more with and from each other and for sharing solutions.
- Bolstering **public safeguarding of the structural safety** of existing structures. Many municipalities and other asset owners obviously do not have the experts in-house to assess this themselves and often do not have the expertise to act as a qualified commissioning party either. A national or regional joint service, comparable to a security region, could provide for this. This service could act as a central asset management unit (see above) for some of the asset owners and provide substantive expertise in the event of incidents.
- **Pooling knowledge development and innovation**. In the current situation, the larger asset owners each chart their own course, while the smaller ones leave innovations to the larger ones. Setting up a joint multi-year programme for knowledge development and innovation would increase the efficiency and quality of both. Cooperation between the members of the ‘golden trinity’ (government bodies, the private sector and knowledge institutions) is desirable, as it is in the top sectors. A common national approach already exists for four types of structure:

    - COB, for underground infrastructure
    - The Asphalt Impulse, for road surfacing
    - The Hydraulic Structures knowledge programme (set up by Deltares, Marin, RWS and TNO), for locks, dams, flood defences and sheet piling
    - The RIONED Foundation, for sewerage and urban water management

  A similar approach for bridges, viaducts and quay walls is lacking. The Building and Technology Innovation Centre (BTIC) is taking the initiative to set one up on the basis of the 'golden trinity'.[25]
- **Training** many more engineers who are experts in the assessment of existing civil structures and who will improve asset management at the area level. Current curricula do not pay enough attention to replacement and renewal. The number of experts in this specialism in the Netherlands should probably increase tenfold, from 20 to 200.

[25] The BTIC is a joint initiative of the Ministries of Economic Affairs, the Interior and Kingdom Relations and Infrastructure and Water Management (I&W), Bouwend Nederland (the Dutch Construction and Infrastructure Federation), NLIngenieurs (the Dutch Engineering Federation), Techniek Nederland (the Dutch Technology Federation), TNO, 4TU.Built Environment and the Netherlands Association of Universities of Applied Sciences.

8 Circular and sustainable

The replacement challenge must be circular and low-carbon. After all, the Netherlands has ambitious targets to reduce CO_2 emissions by 49% by 2030 and by 95% by 2050.[26] Moreover, the Netherlands wants to halve the use of primary raw materials by 2030 and have a fully circular economy by 2050. Obviously, infrastructure managers are also expected to contribute to this.

Circularity has two underlying goals:[27]
- Security of supply of materials, including raw materials
- Reduced burden on the environment of the use of materials

As regards the security of supply of materials and raw materials for civil infrastructure, the scarcity of some critical metals presents the only genuine risk factor. This, in a nutshell, is the outcome of a study commissioned by Rijkswaterstaat into the security of supply of its building materials.[28] Lack of some critical metals can affect the production and quality of steel, metal structural parts and electrical equipment. This, incidentally, is a risk factor that is not unique to civil infrastructure.

The second goal of circularity is to reduce environmental pollution. At Rijkswaterstaat, 95% of the burden on the environment of the use of materials is caused by four applications: asphalt, concrete, crash barriers and lighting columns.[29] The greatest contribution to the burden on the environment is formed by CO_2 emissions, which usually account for half or more of the total burden on the environment of infrastructure projects.

As a result of construction, management and maintenance, civil infrastructure emits about 2–3 megatons of CO_2 annually.[30] This is 1–1.5% of the national total. The main sources of CO_2 emissions are fuel used for construction equipment, electricity consumption, asphalt and cement. Together, they account for more than 90% of greenhouse gases emitted by the infrastructure industry.

There is no shortage of ideas, pilot projects and partnerships for circular and climate-neutral infrastructure.[31] This creative phase is the right way to start any innovation process. The second phase is now under way as well. The emphasis in

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[26] Compared to 1990. As a result of the European Green Deal, the reduction target for 2030 will probably be raised to 50–55%

[27] See PBL's, TNO's and CBS' *Circular economy target for 2030* (Kishna et al, 2019), among others.

[28] Levels-Vermeer and Simons, 2018. See also Appendix B.

[29] Levels-Vermeer and Simons, 2018. See also Appendix B. The burden on the environment was determined using the Environmental Cost Indicator (ECI), which measures 11 environmental impact factors. Direct energy use is not included in the ECI.

[30] Appendix B.

[31] Devised by the private sector, asset owners, knowledge institutions and intermediary organisations such as Bouwcampus, Green Deal Sustainable Civil Engineering, Betonakkoord (the Dutch Concrete Industry Platform), the movement for New Economy entrepreneurs MVO Nederland, Bouwend Nederland, WoW, CROW, Pianoo, BTIC and Bouwagenda. For a substantive overview, see Ministry of I&W, 2020a.

this phase is on selecting the most promising options through practical tests and evaluations. The wheat must be separated from the chaff.[32]
Now comes the third phase, consisting of steps towards upscaling and making sustainable innovations standard practice. The initiative lies with the infrastructure asset owners, which are being called on to innovate their own working methods and systematically prescribe and reward circularity and sustainability in tenders. Sustainable procurement will have to be the consistent norm for at least a number of years.[33] Only a concrete market perspective will incentivise the private sector to start investing in, for example, electrical construction equipment and circular concrete. The transparent and predictable rewarding of sustainability in tenders is the necessary capstone of the innovation process for circular and climate-neutral infrastructure. The market forces thus unleashed will lead to the best innovations coming to the surface and creating incentives for further knowledge development and innovation.

The first step towards circular construction is to use existing infrastructure for a longer period of time. This saves raw materials and energy and is usually cheaper. For this reason, determining the technical service life is also a priority when making infrastructure more sustainable. The aim is to avoid premature replacement. An example is the renewal of the Keizersveer Bridges that form part of the A27. At present, opportunities are being sought to give these bridges a new lease of life at another location. However, continued use of the existing bridges in their current location is arguably a more circular and cheaper solution.

[32] Appendix B gives an overview of the main ways to make infrastructure more sustainable.
[33] The steering group of the Sustainable Civil Engineering Green Deal 2.0 has elaborated the outline into a practical proposal.

9 Signatures

Delft, 8 November 2021 TNO

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op 2021-11-12 13:45:42

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Appendix A Value and costs of civil infrastructure

This appendix explains and substantiates the figures for the value and costs of civil infrastructure quoted in the main text.

Value

Table A.1 gives an overview of the value of different categories of infrastructure. This is followed by an explanation.

Infrastructure	EUR (billions)	Source
Civil infrastructure	406	CBS
Publicly owned civil infrastructure	283	CBS
Privately owned civil infrastructure	35	CBS
Infrastructural and hydraulic structures	73	Bloksma and Westenberg, 2021
Dry structures	67	"
Wet structures	6	"
Rijkswaterstaat structures	58	RWS 2020

Table A.1: Value of different categories of infrastructure.

The value of all civil infrastructure in the Netherlands is EUR 406 billion.[34] This amount is derived from Statistics Netherlands (CBS) figures on the civil infrastructure capital stock. In addition to civil infrastructure, this also includes infrastructure for energy, ICT and the water supply.

The value of publicly owned civil infrastructure is also based on CBS figures on the civil infrastructure capital stock. The assumption here is that government bodies only own civil infrastructure, so no infrastructure for drinking water and energy. This amount is identical to that of the CBS figures on the government balance sheet. The value of civil infrastructure managed by semi-public bodies is also based on the civil infrastructure capital stock, specifically for the transport and storage industry. It is assumed that this infrastructure is entirely in the hands of semi-public bodies, including Amsterdam Airport Schiphol and port authorities. Infrastructure for the energy supply, telecommunications, mineral extraction and water supply is assumed to be owned by semi-public bodies or private sector parties other than those active in the transport and storage industry. This infrastructure is therefore not included in civil infrastructure.

[34] CBS figures for 2018. 'Civil infrastructure' includes the costs of constructing streets and sewerage and preparing the construction sites. Also included are public monuments that are not classified as dwellings or other buildings; shafts, tunnels and other structures in connection with the extraction of mineral and energy resources; and the construction of sea defences, dykes and storm-surge barriers that are intended to improve nearby land that is not itself part of civil infrastructure. Examples are motorways, streets and other roads, railways, airport runways, bridges, elevated roads, tunnels and subways, waterways, harbours, dams and other water works, long-distance pipelines, communication lines, power lines, local pipelines and cables, additional works, and structures for mining, industry or sports and recreation.

The government balance sheet is based on the related CBS figures. To keep the balance sheet accurate, the value of semi-public bodies has been added to non-financial assets and subtracted from financial assets (participating interests).

Costs

Table A.2 gives an overview of the expenditure on civil engineering works in 2019.[35] Of the total EUR 17.2 billion, EUR 15.1 billion was for civil infrastructure (excluding energy and water supply). Of this, EUR 1.4 billion was for civil infrastructure replacement.

Commissioning party	EUR (billions)	Nature of the work	EUR (billions)
Central government	1.7	**New construction**	4.4
Local government bodies	7.3	**Reconstruction**	3.6
Private sector	8.2	**Replacement**	1.6
		Maintenance	7.6

Submarkets	EUR (billions)	Region	EUR (billions)
National roads	1.6	**North**	2.1
Railways	1.4	**East**	3.8
Municipal roads	2.3	**Randstad North**	4.1
Sewerage	1.6	**Randstad South**	3.5
Flood defences	1.8	**South**	3.7
Energy and water	2.1		
Other	6.4		

Table A.2: Civil engineering works in 2019 (EIB, 2020).

Research by CE Delft and Vrije Universiteit Amsterdam for the then Ministry of Transport, Public Works and Water Management estimated the annual costs of transport infrastructure alone at EUR 17 billion (construction, renewal, management and maintenance; 2010 figures).[36] If the infrastructure costs for rail, flood prevention, energy, sewerage and water supply are also added, the annual civil engineering work costs are significantly higher than the above Economic Institute for the Construction Industry (EIB) figures. This large difference is probably due to the methodology used. EIB looks at actual financial flows in a year. CE/VU Amsterdam took an economic approach based on the opportunity costs of the infrastructure investments made.

35 EIB, 2020.
36 CE Delft and VU Amsterdam, 2014.

Appendix B Circularity and CO2 emissions of civil infrastructure

This appendix provides a brief overview of the material flows, CO_2 emissions and burden on the environment with regard to civil infrastructure. National figures are only available for the construction industry as a whole, including for the construction of both residential and non-residential buildings. Several studies provide information on part of the infrastructure. The figures are followed by a summary overview of opportunities to reduce the burden on the environment and improve circularity.

CO_2 emissions

The share of the construction industry in national CO_2 emissions is 2% (Table B.1). Of this, more than 80% is caused by the production of building materials plus the fuel consumption of construction equipment.

CO_2 emissions	CO_2 (megatons)	In %, for the construction industry	In %, for the Netherlands
Construction, including building materials and mobile construction equipment	3.9	100%	2%
Building materials	*1.8*	*47%*	
Mobile construction equipment	*1.5*	*37%*	
Construction companies	*0.3*	*8%*	
Other	*0.3*	*8%*	
Road traffic	29.8		17%
Residential heating	13.3		7%

Table B.1: Share in CO2 emissions of the construction industry (Pollutant Release and Transfer Register 2020; 2018 figures).

In 2010, CO_2 emissions from road infrastructure alone were estimated at 2.2 megatons.[37] This was about 1% of total Dutch emissions and 7% of CO2 emissions from road traffic using this infrastructure. Construction equipment accounted for 41% of emissions, with electricity consumption for lighting and traffic management in second place (Table B.2). The latter is not included in Table B.1.

[37] Keijzer and Leegwater, 2012.

Application	% of the total
Construction equipment	41%
Lighting and traffic management	22%
Asphalt	14%
Clinkers and concrete paving stones	11%
Infrastructural and hydraulic structures	5%
Other	8%
Total road infrastructure	100%

Table B.2: Distribution of greenhouse gas emissions caused by road infrastructure (Keijzer and Leegwater, 2012; 2010 figures).

The CO_2 emissions of Rijkswaterstaat alone were calculated at 0.7 megatons.[38] Table B.3 gives an overview of the largest shares. Almost half was caused by the use of asphalt, concrete and steel. Over 40% was caused by fuel consumption and the remainder by electricity consumption.

Application	CO_2 (kilotons)	% of the total
Road surfacing (asphalt and road foundations)	197	28%
Coastline and navigation channel maintenance	191	27%
Structures (steel and concrete structures, excluding construction sites)	154	22%
Construction sites (earth-moving and other mobile equipment)	74	10%
Electricity (road lighting, traffic management etc.)	52	7%
Government Shipping Company	35	5%
Vehicle fleet (road inspectors etc.)	9	1%
Total for RWS, excluding buildings and mobility	712	100%

Table B.3: CO2 emissions by RWS (Ministry of I&W, 2020c; 2019 figures).

Circularity

The construction industry generates considerable materials flows (Table B.4). In this overview report compiled by CBS, the main flows involve concrete, asphalt, stone and wood. Secondary material use is also considerable, accounting for 38% of the total materials used by the construction industry.[39]

[38] Ministry of I&W, 2020c. Buildings and employee mobility only. Hauck et al (2020) calculated the climate impact of road surfacing works carried out by RWS in 2019 at 223 kilotons Co2-eq$_2$-eq.

[39] CBS 2019.

Material flows in the construction industry	Megatons of material	In %, for the Netherlands
Total materials used	81	48%
Primary	50	
Secondary	31	60%

Table B.4: Share of material flows in the construction industry (CBS, 2019; 2016 figures).

For civil infrastructure, the main material flows involve soil, sand, concrete, asphalt and metals. Soil, sand, asphalt and concrete are moved in large volumes. The volume of metals is modest by comparison, but they place a high burden on the environment over their entire life cycle.

The province of South Holland mapped the material flows for management, maintenance and replacement of the provincial infrastructure.[40] Some results of this detailed survey are summarised in Table B.4. The materials used totalled 204,000 m³. Of this, 68% were primary and 32% secondary materials. The materials released totalled 413,000 m³. This exceeds the volume of materials used, because mud is released during the maintenance of waterways. Of the total materials released, 46% were reused, 39% recycled, 7% landfilled and 6% 'left over'.

Materials used	240,040 m^3	Materials released	415,300 m^3
Primary	**68%**	**Reuse**	**46%**
Asphalt	22%	Mud	33%
Sand	21%	Sand	12%
Salt	10%	**Recycling**	**39%**
Concrete	7%	Asphalt granulate	22%
Secondary	**32%**	Concrete granulate	13%
Concrete granulate	17%	**Landfill**	**7%**
Asphalt granulate	15%	Mud	7%
		Left over	**6%**
		Salt	6%

Table B.5: Materials used and materials released during the management, maintenance and replacement of infrastructure in the province of South-Holland (Van Engelen and Klaasen, 2020).

RWS also had a materials balance drawn up, summarised in Table B.6.[41] In 2014, RWS purchased 46 megatons of material in total. The vast majority of this was sand and gravel, materials that are not included in Table B.4. Table B.6 also shows the

[40] Van Engelen and Klaasen, 2020.
[41] Levels-Vermeer and Simons, 2018.

burden on the environment[42] associated with the use of materials. Concrete and asphalt place the highest burden on the environment, followed by crash barriers and lighting columns.

Material	Megatons	In % RWS	ECI in % RWS
Sand and gravel	42	92%	0%
Asphalt	2.7	5%	29%
Cement and concrete, including reinforcement	0.9	2%	32%
Steel slag	0.5	1%	1%
Crash barriers	0.1		25%
Lighting columns			9%
Sheet piling			2%

Table B.6: Material use and related burden on the environment by Rijkswaterstaat (Levels-Vermeer and Simons, 2018; excluding transport, 2014 figures).

Besides the burden on the environment, security of supply is the second reason for pursuing circularity.[43] Rijkswaterstaat commissioned research into the materials at risk of disruption to the security of supply.[44] Only critical metals are a risk of scarcity. This can affect the production and quality of steel, metal parts and electronic equipment. This is a risk factor that is not unique to civil infrastructure.

Sustainable infrastructure

In summary, there are no major risks to the security of supply of raw materials needed for civil infrastructure, except for some critical metals. The burden on the environment is mainly caused by construction equipment, electricity for lighting and traffic management, cement, asphalt, road surfacing and metals. This includes the entire life cycle, i.e. construction, use and demolition. CO_2 emissions from civil infrastructure have been estimated at 2–3 megatons, equivalent to 1–1.5% of total Dutch emissions.

The transition to a sustainable infrastructure – circular and low-carbon – primarily focuses on the following materials:

- *Fuels*. Transition to clean fuels for construction equipment, vehicles, dredgers and the like. Some of this will involve green electricity and some will involve a switch to low-carbon synthetic fuels.
- *Asphalt*. Asphalt recycling, as is already being practised on a large scale. Introduction of energy-efficient processes in asphalt plants and in the processing of asphalt. Extension of the service life of asphalt. Development of low-carbon bitumen from natural raw materials. Use of renewable energy in asphalt plants.
- *Cement*. Reuse of the fine fraction from recycled concrete to reduce the use of primary cement. Development of low-carbon binders to replace cement.

[42] Environmental Cost Indicator (ECI).
[43] Kishna et al, 2019.
[44] Levels-Vermeer and Simons, 2018.

Probably the greatest environmental benefit will come from the transition to cement produced without CO_2 emissions.[45] This is possible by using renewable energy and capturing the CO_2 released from the process (CCS).

- *Electricity*. Reduced electricity consumption and switch to green electricity for lighting, controls and traffic management.
- *Metals*. Recycling of metals, as is already being practised on a large scale. Switch to more environmentally friendly materials, for example for crash barriers or lighting columns Reduced use of metal through more ‘economical’ design. Production of low-carbon steel, for example by using hydrogen instead of coke, will also make a major contribution to reducing the burden on the environment.[46]

As explained in the main text (section 8), the way to achieve a circular and low-carbon approach to the replacement challenge is through the commissioning parties’ procurement policies.

[45] Energy Transitions Commission, 2018a.
[46] Energy Transitions Commission, 2018b.

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