URBAN CLIMATE - GLOBAL CLIMATE

The concept of the Frankfurt bridges indirectly makes a positive contribution to the larger urban climate by creating new living space on them without overdeveloping the surrounding area: Cooling corridors in the city can thus be preserved. They can also improve the urban climate on a small scale, since their 1 million square meters of unsealed green bridge surface extend over sealed dark asphalt and provide it with cooling shade. As the carrier of water infrastructure, the bridges also enable the unsealing and irrigation of 40,000 square meters in the city as well as the planting of 1,000 shade trees.

The Frankfurt bridges can be built sustainably and enable the implementation of various climate protection measures, so that their CO_2 balance is reduced by around 75 %. They will also be used to implement numerous innovations from European and German research that will help achieve climate targets worldwide.

Old New Territory Frankfurt

Improvement of the urban climate

The bridge structures are intended to improve the urban climate thermally and in terms of air hygiene - exemplary for the urban planning of the future

Frankfurt: Current urban climate

The Climate Plan Atlas Frankfurt from 2016 shows the need for action - the city and citizens have also already responded successfully with numerous initiatives

Effects of the bridges

Green and unsealed areas are created above heavily sealed roads: The urban climatic balance for the bridges is positive

Measures next to the bridges

The bridge ring line can unseal, plant and irrigate 40,000 m^2 area in Frankfurt, which is also positive for the city climate

The CO_2 balance sheet of the bridges

Numerous measures can be taken to reduce the CO_2 balance of Frankfurt's bridges to one quarter

Urban climate - world climate

In the city of the future, CO_2 emissions can be reduced: Smart urban planning enables the use of renewable energies for transport and utilities

Improvement of the urban climate

In order to improve the urban climate, urban sprawl must be avoided and unsealing and shading of formerly hot asphalted streets must be promoted

The concept of the Frankfurt bridges represents an opportunity for major cities worldwide to defuse the conflict of interests in modern urban planning: If, in the past, people were forced to sprawl into the surrounding countryside at the expense of the city's climate as the population grew, or if already built-up areas in the city becamde denser, now a space that previously had a rather negative effect in the city is being put to positive use: Above dark asphalted streets, Frankfurt's bridges stretch through the city like a green lung with 1 million square meters of greenery. With their water ring, they contribute to further unsealing and greening in the entire inner city area: a completely new and urban climate-friendly form of redensification.

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Chapter content: The chapter provides an overview of the most important factors influencing the urban climate and the role played by bridges in this context

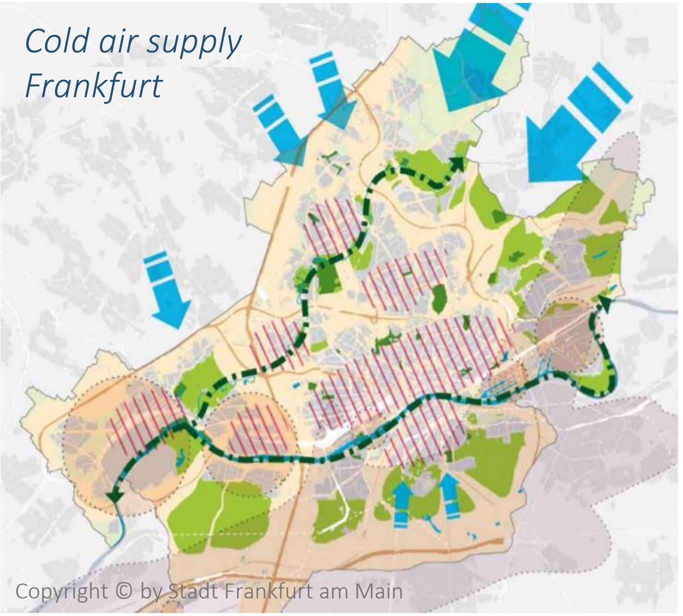
First of all, the result of the analyses on possible consequences of the Frankfurt bridges on the supply of cold and fresh air from the surrounding area is presented. In connection with this, the indirect positive effects of the bridges are described: they help to create living space without urban sprawl and excessive densification in the city.

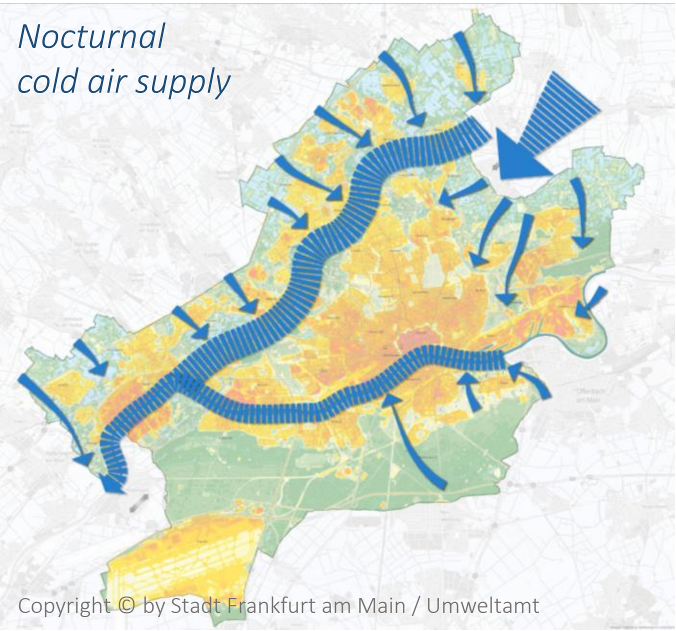
It is then described how Frankfurt's bridges, both as a building and as a network structure, have an effect on various aspects that positively influence the urban climate: The bridges provide a transport landscape without pollutant emissions above conventional traffic with combustion engines; they create unsealed, irrigated areas and increase cooling shading in the city through the bridge's own corpus as well as indirectly through the irrigation of existing and additional urban trees.

Cold and fresh air supply from the surrounding area are important factors for the urban climate

Good urban planning takes these so-called "cold air corridors" into account in any infrastructure project: after all, grassland and wooded areas around cities are capable of producing cool, clean air and should be preserved wherever possible.

The better this cool and fresh air flows into a city along so-called "air corridors" (usually green corridors or rivers), the more pleasant the urban climate becomes. These cold and fresh air corridors should not be built on under any circumstances





Good urban planning therefore avoids urban sprawl in the surrounding countryside

Urban sprawl must therefore be avoided in good urban planning - at least as far as possible.

With the Frankfurt Bridges, a concept has been developed that creates new living space without building on the surrounding area, which is valuable in terms of the city's climate: "cold air formation areas" in the surrounding area can thus be preserved, from which fresh and cool air can flow into the city.

Built-up bridges over traffic roads is a good concept for urban planning in terms of urban climate - worldwide!

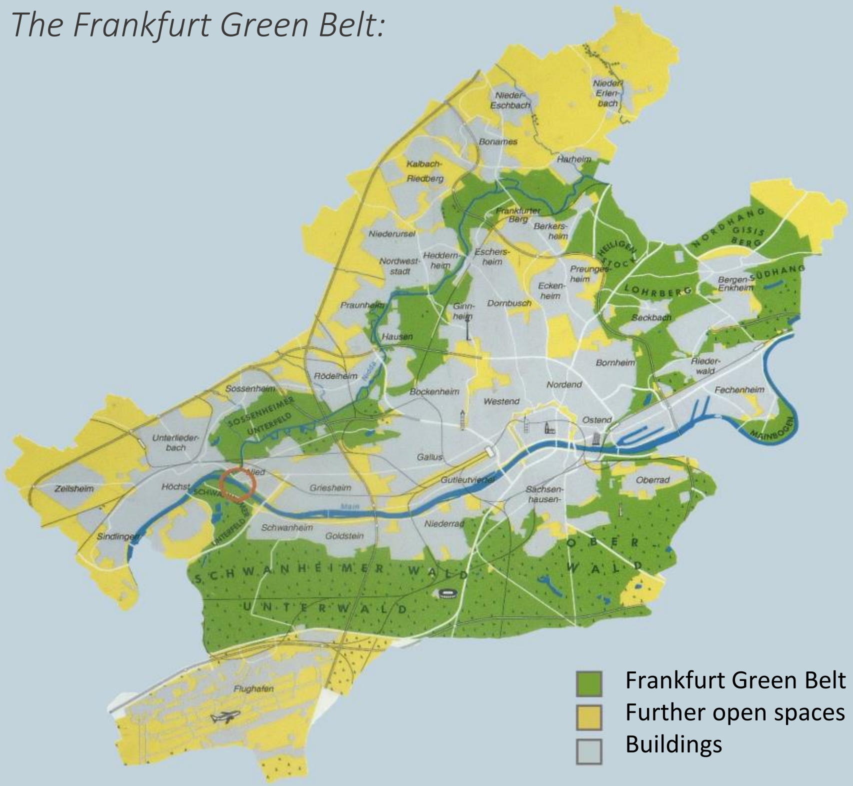
The Frankfurt bridges avoid urban sprawl and are a new, more compatible form of redensification: they thus help to protect the city's cold and fresh air corridors

Successive development of the surrounding area is currently the only solution to growing housing demand in most cities and municipalities - including Frankfurt. This is to change with the bridges: Here, redensification does not take place in already built-up areas, but over dark gray asphalted traffic roads, which in any case have no positive influence on the urban climate. If unsealed and greened bridge areas rise above them, these stretches will then even become "green lungs" for the city.

Old New Territory Frankfurt

In particular, Frankfurt's green belt must be protected from urban sprawl with regard to the supply of cold and fresh air

The Frankfurt Green Belt:



With population growth, every city is usually faced with the dilemma of whether it is better to develop the surrounding areas or to increase the density in the city centre in order to create more living space

More than half of the world's population lives in cities - and by 2050 this figure is expected to rise to two-thirds. To accommodate them all, the only options available so far are either (1) to "redensify" cities, i.e. to build on the last remaining open spaces and, if necessary, to build upwards, or (2) to build on the surrounding countryside, thus sacrificing valuable areas for the formation of cold air. Neither is exactly conducive to the urban climate.

Redensification in already built-up areas occurs sporadically in Europe and, in the case of individual buildings, has no perceptible impact on the urban climate. Applied on a large scale, however, it very quickly becomes problematic for the urban climate, as many high-density cities in Asia or South America show.

The Frankfurt bridges offer a solution to this dilemma, which, according to the analysis, does not noticeably impair the cold air and fresh air corridors of Frankfurt

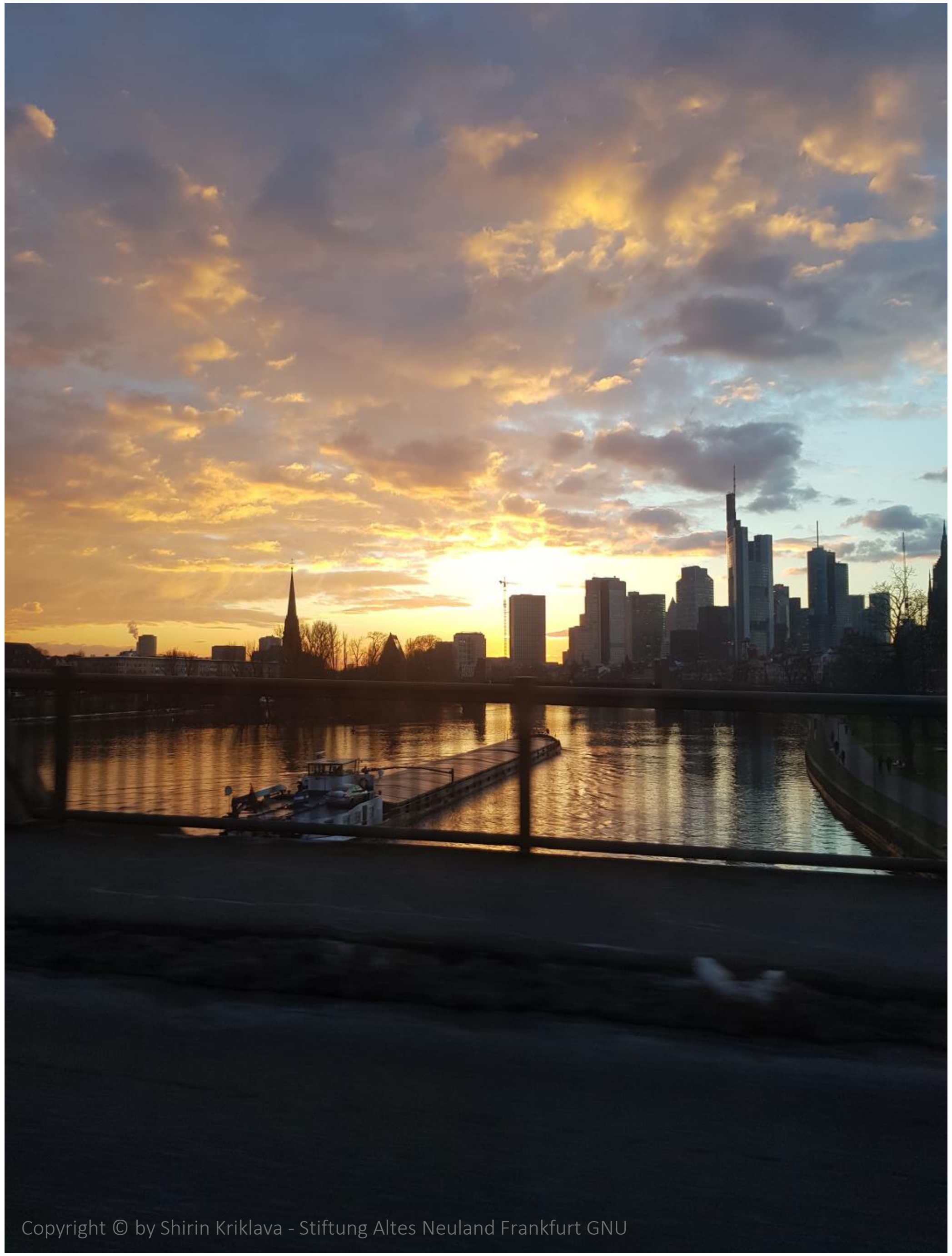
After examining the ventilation and cold air pathways, it can be assumed that the Frankfurt bridges will not have any large-scale influence on the urban climate, as they are too small in terms of area in relation to the total city area and, with an average thickness of the bridge corpus of only two metres, they also do not represent any significant restrictions for the air pathways.

Accordingly, the bridges do represent a form of "densification", but since this densification is accompanied by comparatively low building density and takes place far away from settlement climatic compensation areas - namely above the traffic roads - it is a form of densification that does not affect the urban climate on a large scale.

The effect of the urban climate on humans is complex

In cities, human well-being is shaped by various influences. Of particular importance are not only the thermal conditions, which affect the air temperature But also the air-hygienic situation, which concerns the accumulation of air pollutants, and the characteristics of the wind field are also significantly involved in the perception of the urban climate.

It is therefore not surprising that the ideal of a healthy urban climate is characterised above all by moderate temperatures and pleasant wind conditions, while the air quality should be as good as possible.



A small-scale analysis of the urban climate focuses on the following three aspects: (1) Immission load, (2) Thermal load and (3) Gustiness

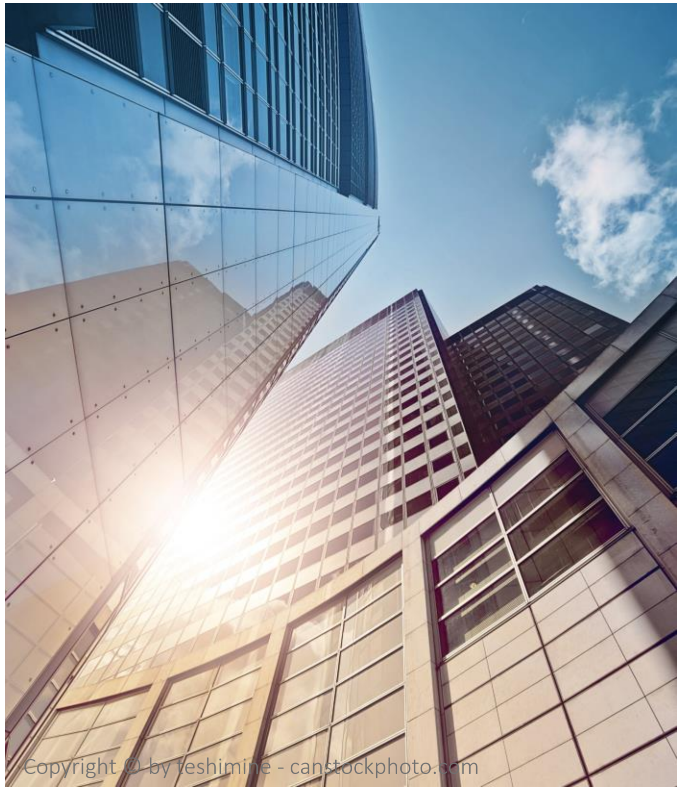
(1) Immission pollution occurs when air pollutants accumulate in the urban atmosphere and do not dissipate. (2) Thermal pollution occurs especially in summer due to strongly heated and stagnant air masses. (3) Unpleasant air currents in the form of gusts often form at the edges of buildings and in street canyons.

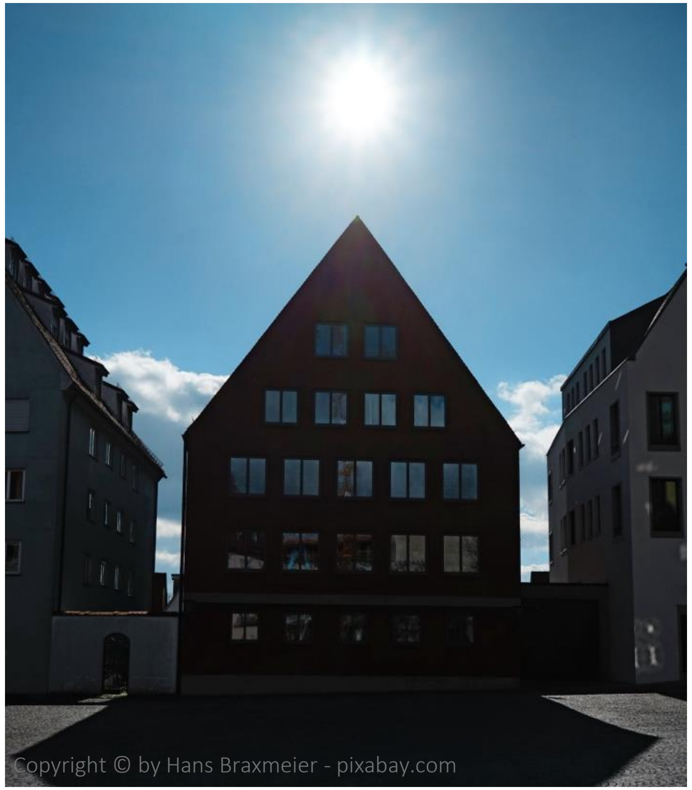
(1) Dense building stock can lead locally to increased immission loads

Buildings are an important factor for the urban climate: if buildings are very close together in certain places, air pollutants can collect there to a greater extent.

(2) Between buildings, the air can hardly circulate and heats up more easily, which can lead to thermal stress locally

At the same time, more and higher buildings also mean increased shadows - which in turn can have a cooling effect. However, shade is usually only really pleasing outdoors, as it is perceived as an impairment of the light situation in built-up areas - at least in Central and Northern Europe.





(3) The local flow situation at a particular location in the city can be significantly altered by new development structures under certain circumstances

On the one hand, a structure can reduce the wind speed close to the ground because the flow path is obstructed. This has a negative effect not only on air hygiene but also on thermal comfort: Air pollutants that are released close to the ground (e.g. exhaust gases from vehicles) can be transported away more poorly. Experts refer to this as "aggravation of the immission situation in the road space".

The local climate also changes when there is no more wind on the ground: heat can no longer be dissipated as well - resulting in more intense heat islands in hot weather.

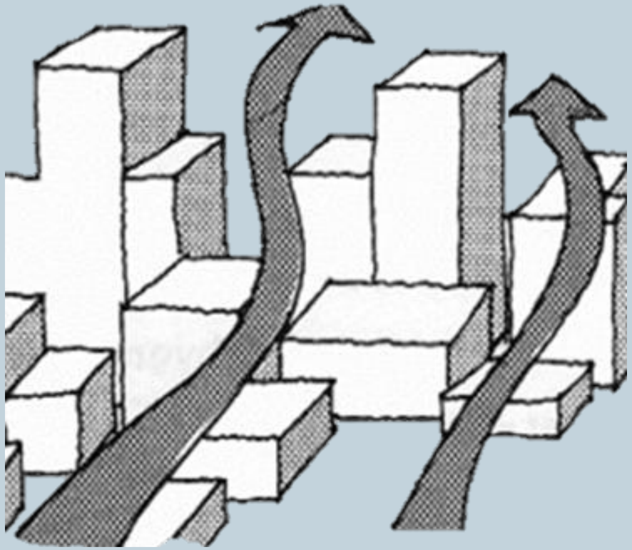
Depending on the situation, however, new development can not only obstruct the wind: on the contrary, it can also ensure that the wind is channelled, catches somewhere and even causes turbulence.

This is positive for air hygiene, because the air pollutants are diluted; the thermal load can also be reduced - especially on hot days - by the increased gustiness: The locality is better ventilated, so to speak. However, strong gusts can also drastically reduce the local comfort factor - despite better air quality and moderate temperatures - at the latest when your sun hat flies off.

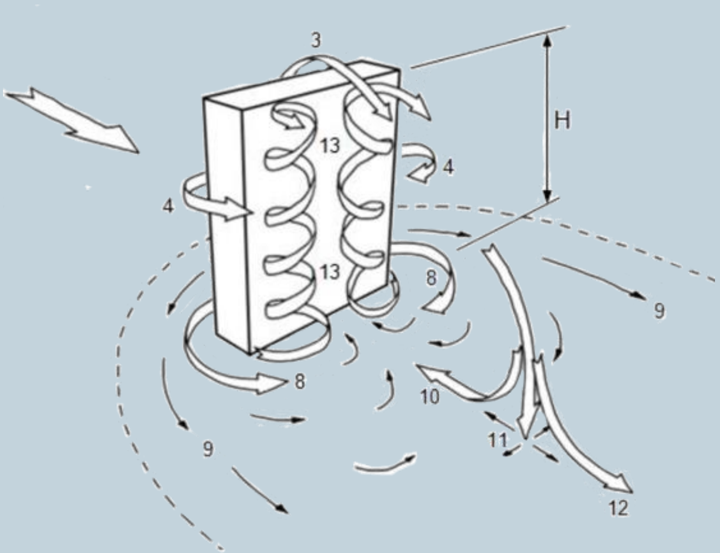
Stream situation according to building structure

The shape and layout of buildings are important factors for the urban climate, especially when it comes to the issue of gustiness

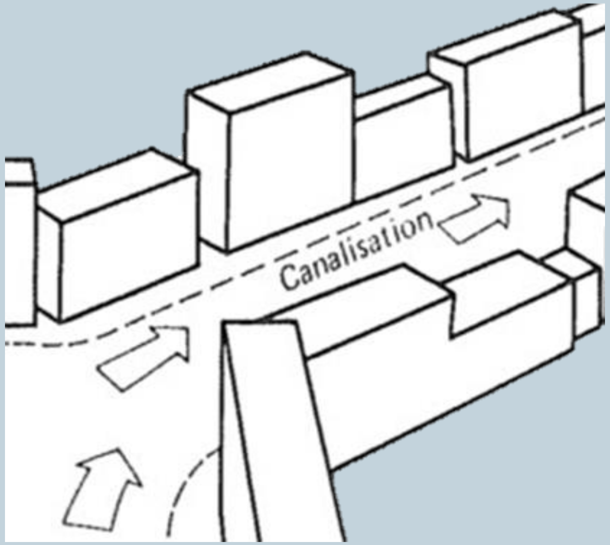
Effects of building shapes and arrangements on gustiness



Overflow of dense building clusters



Flow pattern at solitary structure

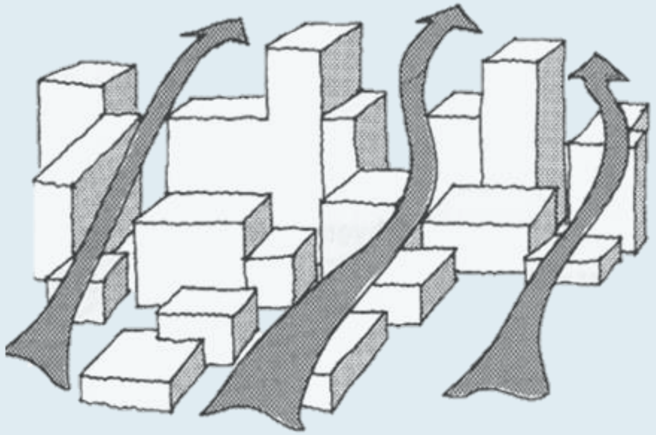


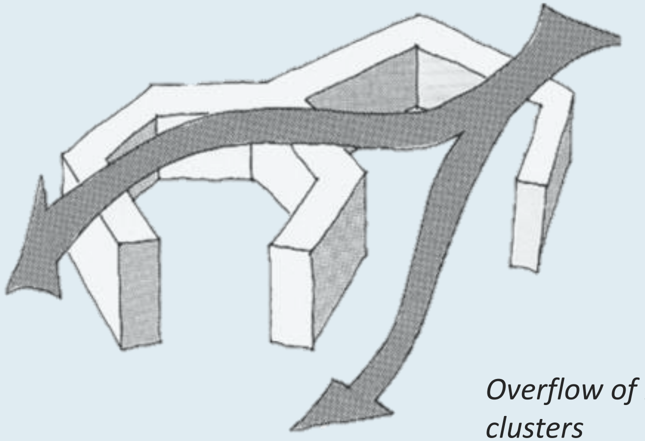
Flow corridors in dense development

Common example: Dense development in particular can lead to turbulence

With dense development, the wind near the ground is disconnected from the overlying flow. This reduces the "wind speed near the ground" and the street space is less well ventilated.

In order to demonstrate the extent to which wind movement in the street canyons will be reduced, flow and climate models can be used to simulate the conditions before the start of the construction phase. In this way, it is possible to estimate in advance of the construction measures how the air currents will behave on a small scale at the individual locations in the city.



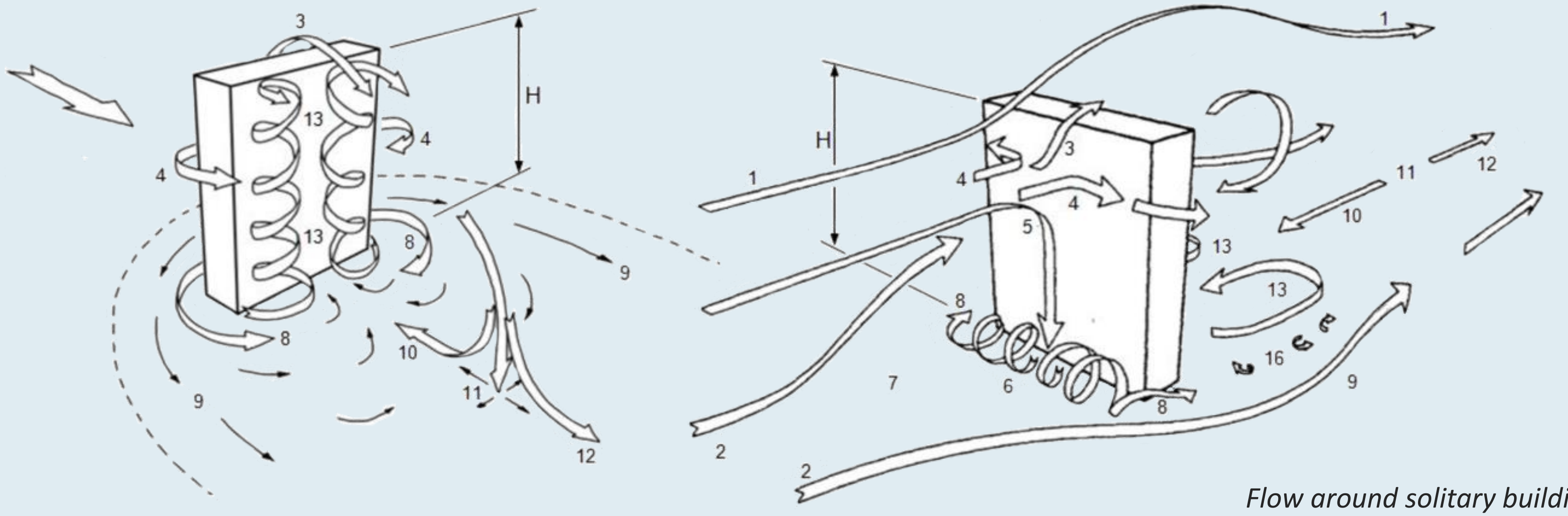


Overflow of building clusters

However, turbulence does not only occur with dense development, but also with the exact opposite: the solitary buildings

If individual buildings protrude above the average building height, as is the case with some high-rise buildings in Frankfurt, very turbulent flows can occur in the vicinity of these solitary buildings close to the ground due to the downward deflection of the upper flow into the street space: Complex turbulences then occur when flowing around the edges of the building and downwind of the structure. This leads to a strong increase in local gustiness. Anyone walking through the skyscraper canyons in Frankfurt can sometimes feel this very rudely.

Although the Frankfurt bridges are not solitary structures, similar effects can also occur as a result of plateaus, such as the planned bridge structures. Therefore, the complex flow conditions caused by the bridge structures must also be thoroughly investigated and simulated in the course of the preliminary planning.

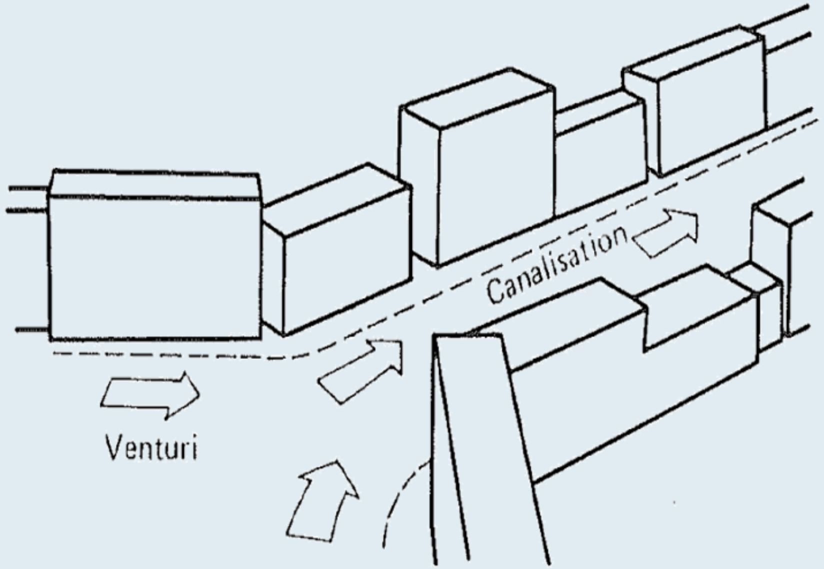


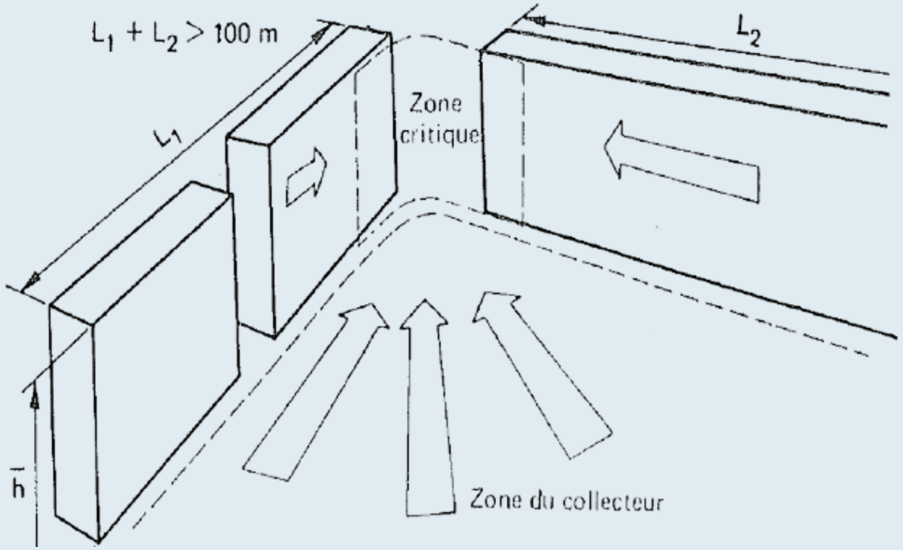
Flow around solitary buildings

And sometimes wind and turbulence fields occur below the "mean roof level" - i.e., on the façade below the edge of the roof

Experts refer to this as channeling and jet effects: The wind whistles through the road as through a channel. The narrower the channel becomes - or even if two channels (i.e., roads) merge into one channel - the flow velocity increases and the so-called "Venturi effect" occurs.

In any case, this effect will be investigated for the bridges during the preliminary planning by means of flow simulations. Although road traffic under the bridges remains largely unaffected, such flows could become very unpleasant for pedestrians.





All three aspects that affect the urban climate locally can be significantly mitigated by a high proportion of vegetation area in the city

Vegetated areas have several advantages: in a city park, for example, there are no cars and there are no other potential sources of pollution.

Unsealed and greened areas do not heat up as much and therefore represent so-called relief areas and counteract urban overheating.

Parks have trees and bushes instead of buildings, so that there is no gustiness due to canyon shapes and the like.

Accordingly, every city can positively influence its urban climate by increasing the proportion of inner-city vegetation areas.

The Frankfurt bridges, with their 1 million square metres of green surface, represent an extension of the urban vegetation areas

Overall, the bridges do not have a negative impact on the urban climate: neither do they increase the accumulation of pollutants, nor do they lead to heat islands, nor do they favour gusts - on the contrary: some feel-good factors, such as cool and "fresh" (i.e., low-pollutant) air , can be favoured by the bridges.

The shadows cast by a building keep it cool: and Frankfurt's bridges shade the streets below them, which would otherwise heat up in the blazing sun.

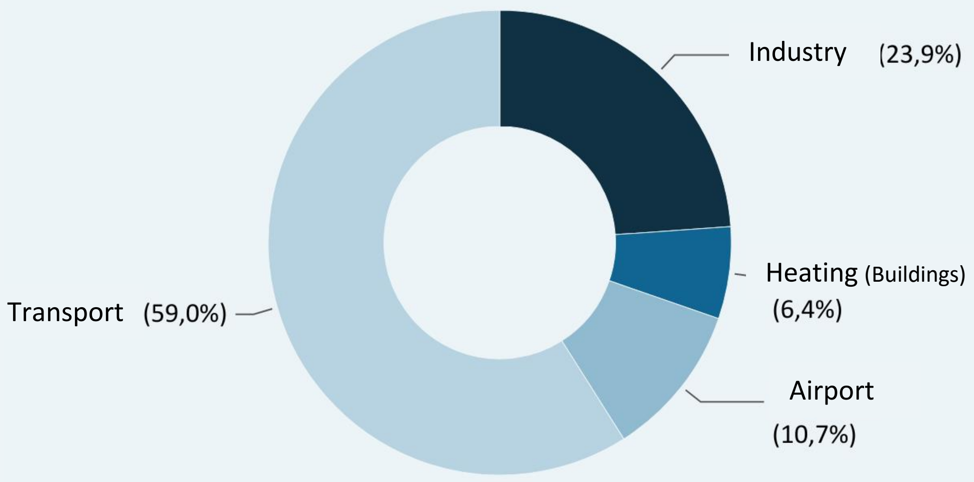
Unsealed surfaces that can absorb rain and irrigation water also contribute to a pleasant local climate with evaporative cooling: And the surfaces of the bridges are unsealed wherever there is not a vehicle driving or a house standing.

The bridges also offer many advantages due to their net character

The Frankfurt bridges are not only positive for the city climate as a shaded, greened and irrigated structure in themselves: they also open completely new possibilities as a special unique infrastructure system for the city by (1) providing a platform for emission-free traffic, (2) irrigating unsealed areas in the city, (3) thereby enabling more shady tree cover in the city and (4) also transporting water to a variety of fountains and newly created water bodies.

(1) Zero-emission bridge traffic helps reduce the use of internal combustion engines in the city

Shares of annual NOx emissions of the main emitters in the Rhine-Main conurbation



Quelle: HMUKLV • Erstellt mit Datawrapper

In most cities, motor vehicle traffic is the main emitter of nitrogen oxides and is also largely responsible for fine and coarse particulate pollution. In the Rhine-Main region, too, traffic is the largest polluter in the ground level.

With their zero-emission hydrogen and electric vehicles, the Frankfurt bridges not only provide climate-friendly local transport for the bridge district, but also relieve the strain on the road traffic that flows beneath them with around 30 million passenger journeys a year - and thus help to reduce pollution in the city.

The solar energy generated on the bridges is used, among other things, for hydrogen production and thus also enables numerous hydrogen filling stations for traffic on the ground. For e-cars, there are charging options at hundreds of bridge piers, which also promotes the move away from the internal combustion engine.

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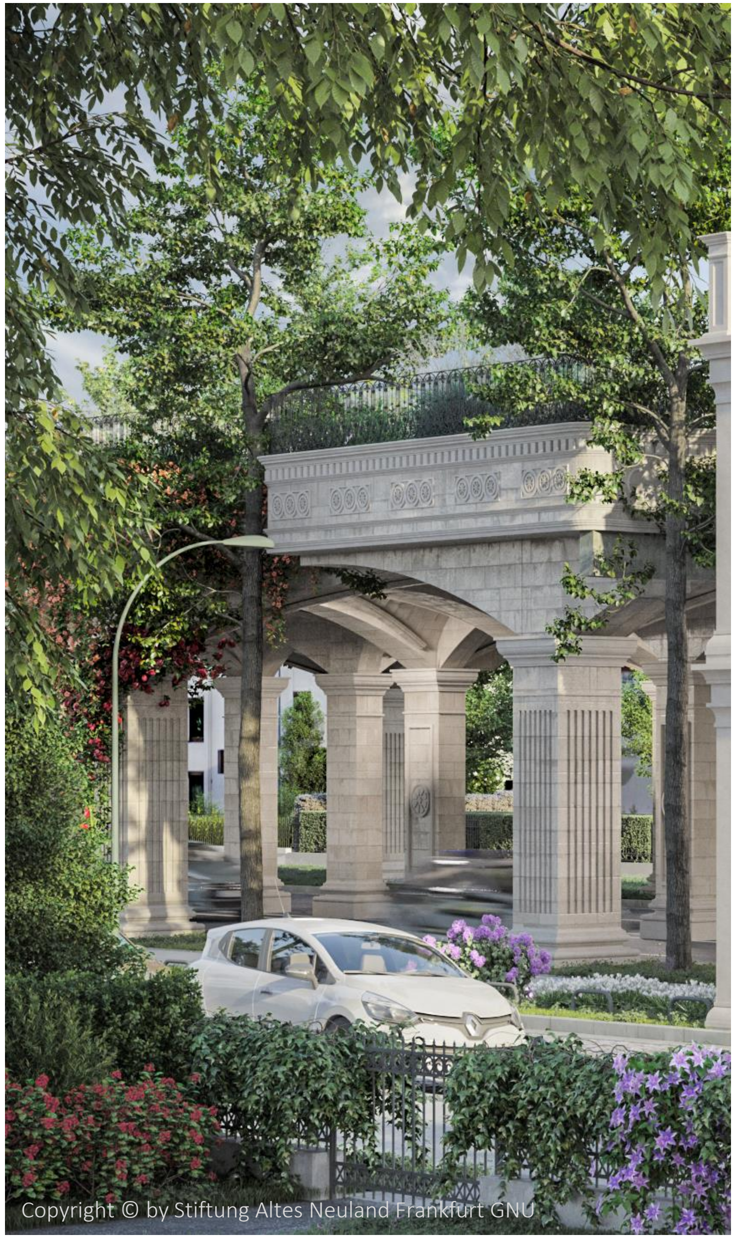
Frankfurt



(2) The bridges have a positive impact on the areas along their course

In addition, the bridges as a structure along their course make a positive contribution to the urban climate: by irrigating the green areas to the right and left of the bridge as well as many unsealed areas in the city, their positive effect extends beyond their own bridge corpus.

(3) The bridge as an irrigation infrastructure helps in reducing thermal load in the city

Good urban planning provides for unsealing and planting of road surfaces, because soil does not store heat as strongly as asphalt. This has a cooling effect, especially at night. If the soil is also wetted or soaked by irrigation water or rain, then it serves as a particularly intensive cooling surface.

The most effective way of providing thermal relief is to plant large-crowned trees, because trees cast shade, and this cools streets noticeably.

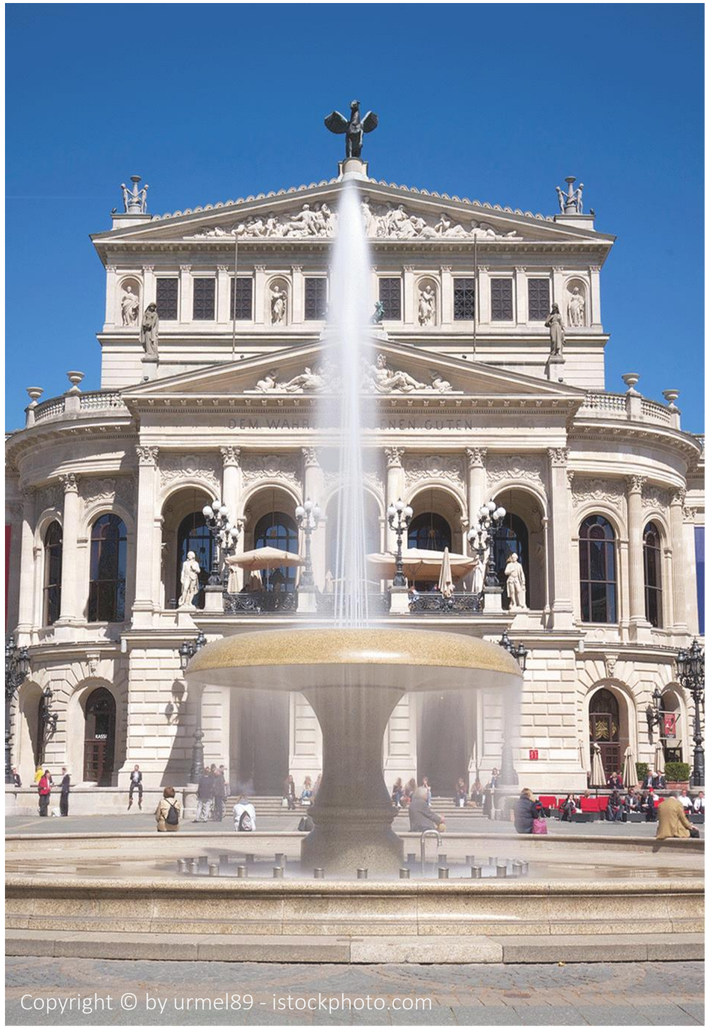
However, urban planning must be carefully considered here, because not all trees are the same: some trees emit trace gases from which ozone is formed in sunny weather; others have such dense crowns that - especially when planted in rows as avenues or at bottlenecks - they act as flow obstacles and keep out cooling winds. Tree selection must therefore be carried out with professional support.

(3) The bridges help the city to have more trees

The bridges are crisscrossed by a water ring main that allows them to bring water to the city over a wide area.

They enable the irrigation of 40,000 square metres of unsealed area and the planting and irrigation of around 1,000 additional trees in the city centre - thus making a significant contribution to increased shade in the city.

(4) With the help of a water supply structure such as the bridges, urban planning can also create more fountains, misting systems or even water areas to cool down on hot days



The bridges' ring mains can supply water for hundreds of fountains or fogging systems. It also feeds the new bathing lake on the Nidda.

But all these water-cooling sources must be carefully planned, because under certain weather conditions they can also have the opposite effect: Because evaporation can also lead to muggy air instead of the cool breeze.

Conclusion: Frankfurt's bridges do not have a negative overall impact on the city's climate

The Frankfurt bridges do not affect Frankfurt's cold and fresh air corridors to any perceptible extent - quite the opposite: as they represent a concept to avoid urban sprawl in the surrounding area and to relieve the city during redensification, they have a positive long-term effect on the supply of cold and fresh air. They also offer more advantages than disadvantages in terms of microclimate: they hardly increase the accumulation of pollutants, but at the same time promote coolness through shade cast by their own corpus as well as newly planted irrigated trees; likewise, they create a pleasant urban climate through unsealed, greened and irrigated areas.

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THE PLAN

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WATER

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Urban Climate - Global Climate: Old Uncharted Territory Worldwide


The goal: to arm the city against drought and floods


The green metropolis of the future


Vitalization of the urban green

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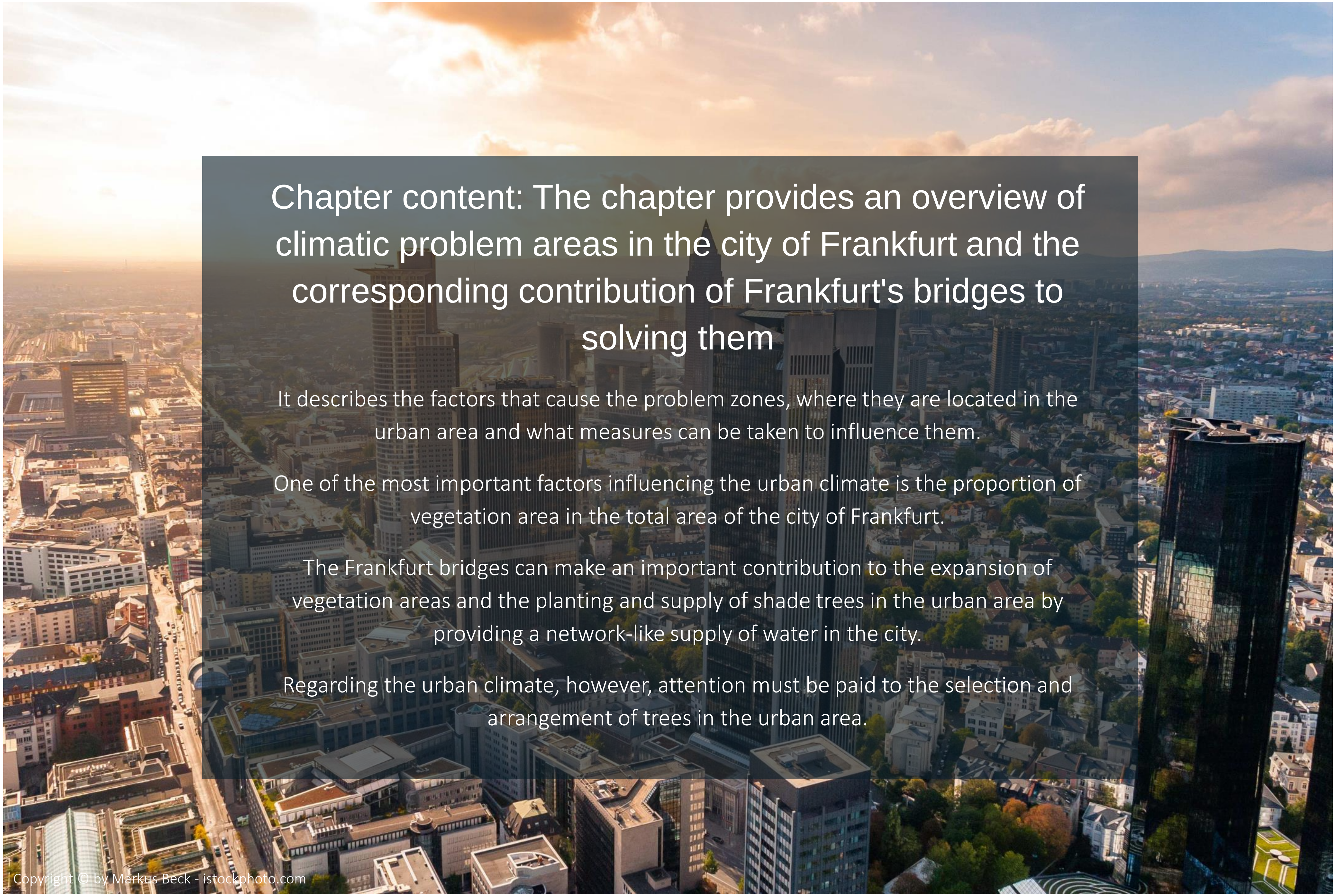
Frankfurt: Current urban climate

The urban climatic situation is critical in many places in Frankfurt, especially in the city centre

The Climate Plan Atlas Frankfurt from 2016 shows the need for action - the city and citizens have also already responded successfully with numerous initiatives. In particular, increasing the proportion of unsealed surfaces in the city centre represents an important lever for improving the city's climate - a potential that has not yet been fully exploited, as it has been difficult to secure the water supply for small-scale green areas in particular. With the water supply from the Frankfurt bridges, however, unsealing on a larger scale and planting with shade trees in the city will become possible.

Old New Territory Frankfurt



Chapter content: The chapter provides an overview of climatic problem areas in the city of Frankfurt and the corresponding contribution of Frankfurt's bridges to solving them

It describes the factors that cause the problem zones, where they are located in the urban area and what measures can be taken to influence them.

One of the most important factors influencing the urban climate is the proportion of vegetation area in the total area of the city of Frankfurt.

The Frankfurt bridges can make an important contribution to the expansion of vegetation areas and the planting and supply of shade trees in the urban area by providing a network-like supply of water in the city.

Regarding the urban climate, however, attention must be paid to the selection and arrangement of trees in the urban area.

Frankfurt is not only dense in the city centre, but also highly built-up due to its high-rise buildings

Building density, the proportion of parking space and numerous other factors have an impact on the urban climate in city locations.

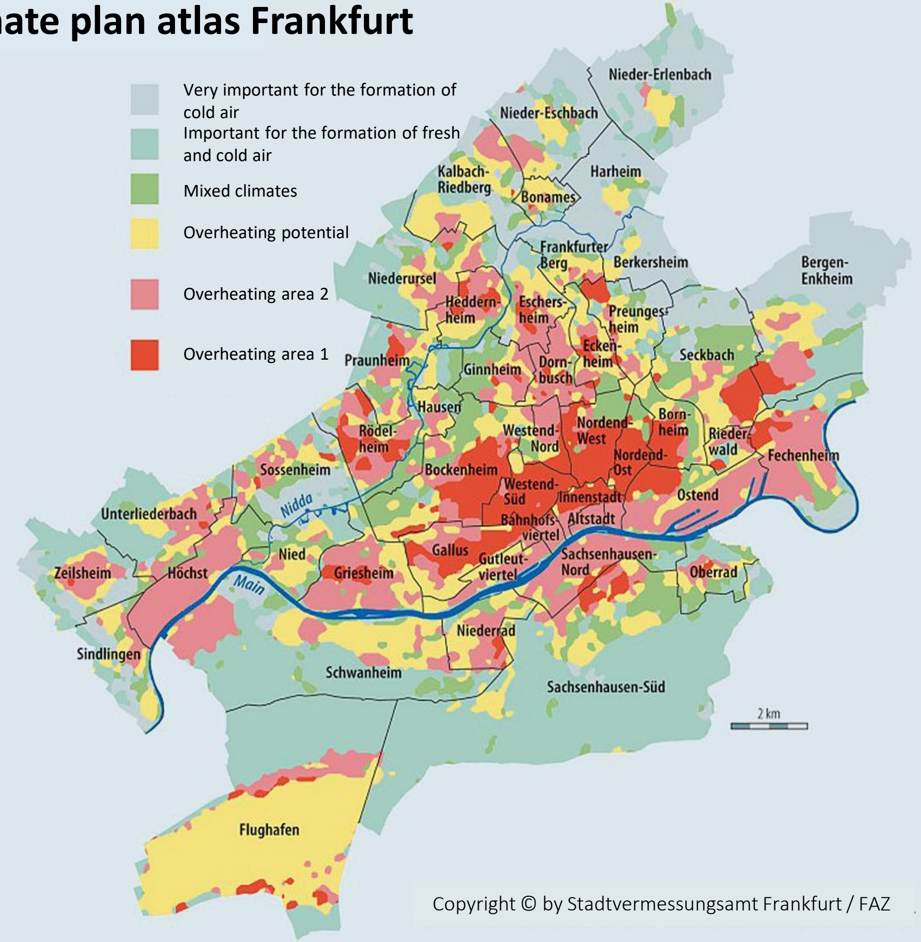
In Frankfurt, there are hardly any vegetation areas between the Alter Oper and the Konstablerwache - at the same time, precisely this area is particularly densely built up with high-rise buildings.

Even though the streets from Fressgasse to the beginning of the Zeil are designated as pedestrian zones, these areas to the north and south are nevertheless surrounded by heavy traffic.

The consequences for the urban climate can be seen directly in the Frankfurt Climate Atlas

The lack of unsealed and green areas - together with the dense development and the higher traffic volume - leads to increased heat stress in the inner city.

Climate plan atlas Frankfurt



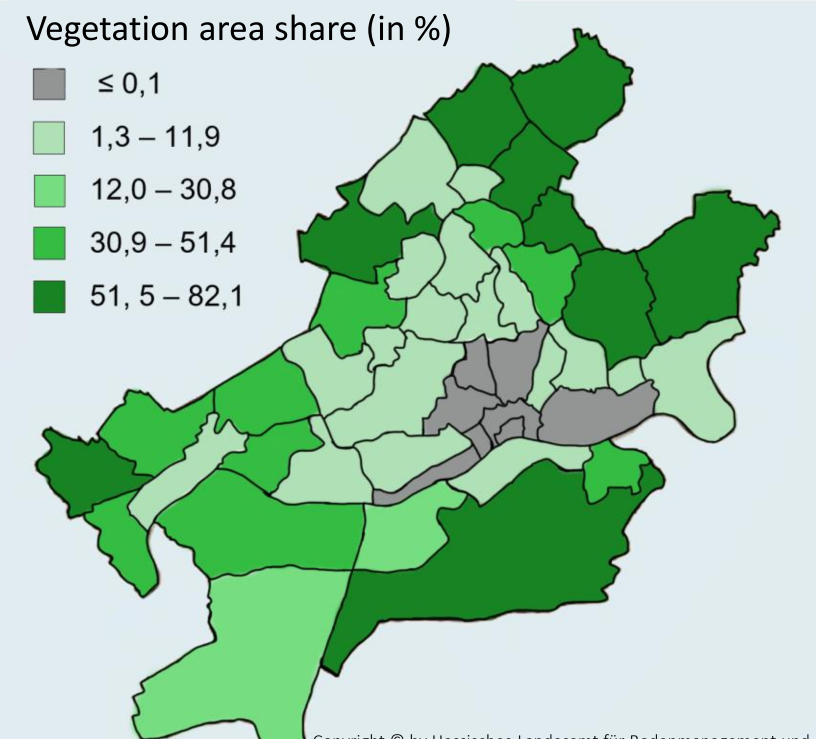
Due to the high degree of sealing and the low proportion of vegetation, there is hardly any evaporation of water, which means that there is practically no natural cooling of the air via plants and the soil. At the same time, the buildings and the traffic on the streets emit a lot of heat. In addition, the heated air can only be exchanged by the wind to a limited extent due to the dense development.

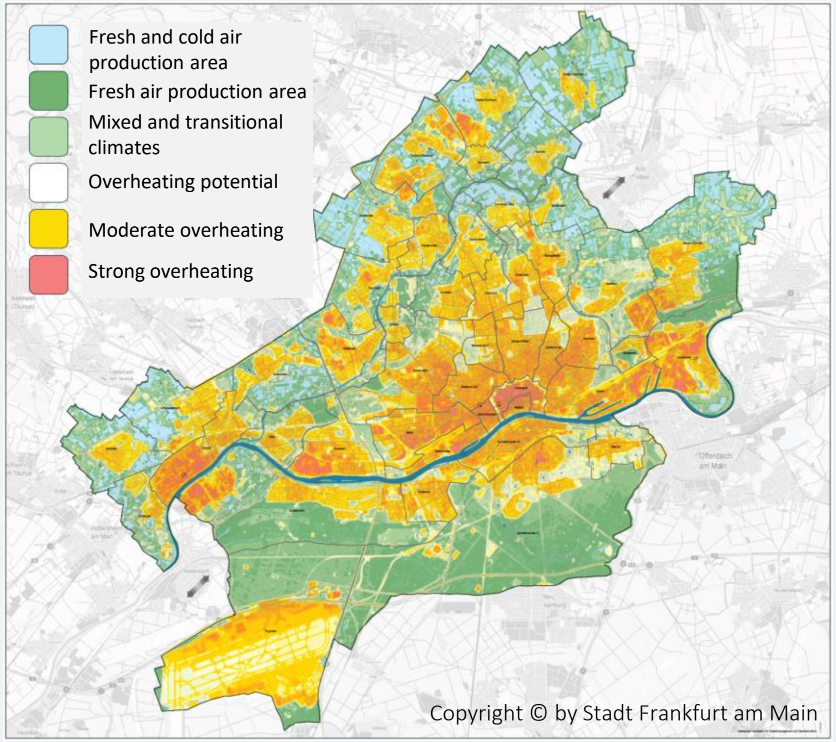
As a result, the heat remains in the city even at night - a heat island forms. Particularly during hot summer periods, this leads to thermal stress on the human body. Frankfurt's densely built-up inner city therefore needs clever ideas that will help the city and its people achieve a healthier and more pleasant climate.

The amount of vegetation in a city is an important factor for the urban climate

When comparing the proportion of vegetation with Frankfurt's climate function map, the spatial correspondence between areas with low green space availability and those with higher levels of overheating is striking. Although there are many other influences on which the characteristics of the urban climate depend, the degree of greenery in a district is one of the most decisive factors, as it has a direct effect on the air temperature.

While vegetated areas in the outer districts of Frankfurt make up more than half of the urban area in some cases, there is hardly any urban greenery in the area of the city centre. This can be quite problematic for the local climate, especially in the summer months.





The total proportion of vegetation area in Frankfurt is 40% - the urban green is just not evenly distributed over the city area

Frankfurt's urban area, with its roughly 250 million m^2 of surface area, consists of almost 40 % so-called "vegetation area" and only another 40 % or so of settlement area (the rest is mainly roads and other sealed surfaces).

Frankfurt's Parks Department maintains 200,000 trees and cares for around 17 million square metres of urban green and open spaces - and all this with just 1.3% of Frankfurt's city budget (which, after all, amounts to almost €4 billion a year). A remarkable achievement, especially as around one fifth of this meagre budget goes on waste disposal.

So actually Frankfurt is already quite extensively greened and maintained. But the feeling of a pleasant urban climate is not evenly distributed in the city.

The city of Frankfurt is already working intensively on "blue-green" solutions

The city of Frankfurt is intensively engaged in projects and actions that promote the city's natural water balance (blue) and thus enable significantly more planting in the urban area (green):
For example, there is an action process called "Frankfurt Green City", which was launched in 2014 and in which many activities are organised, or another initiative of the city, called "Frankfurt frischt auf", where the already existing funding programme for facade greening, roof greening and front and backyard greening is being expanded and further developed.

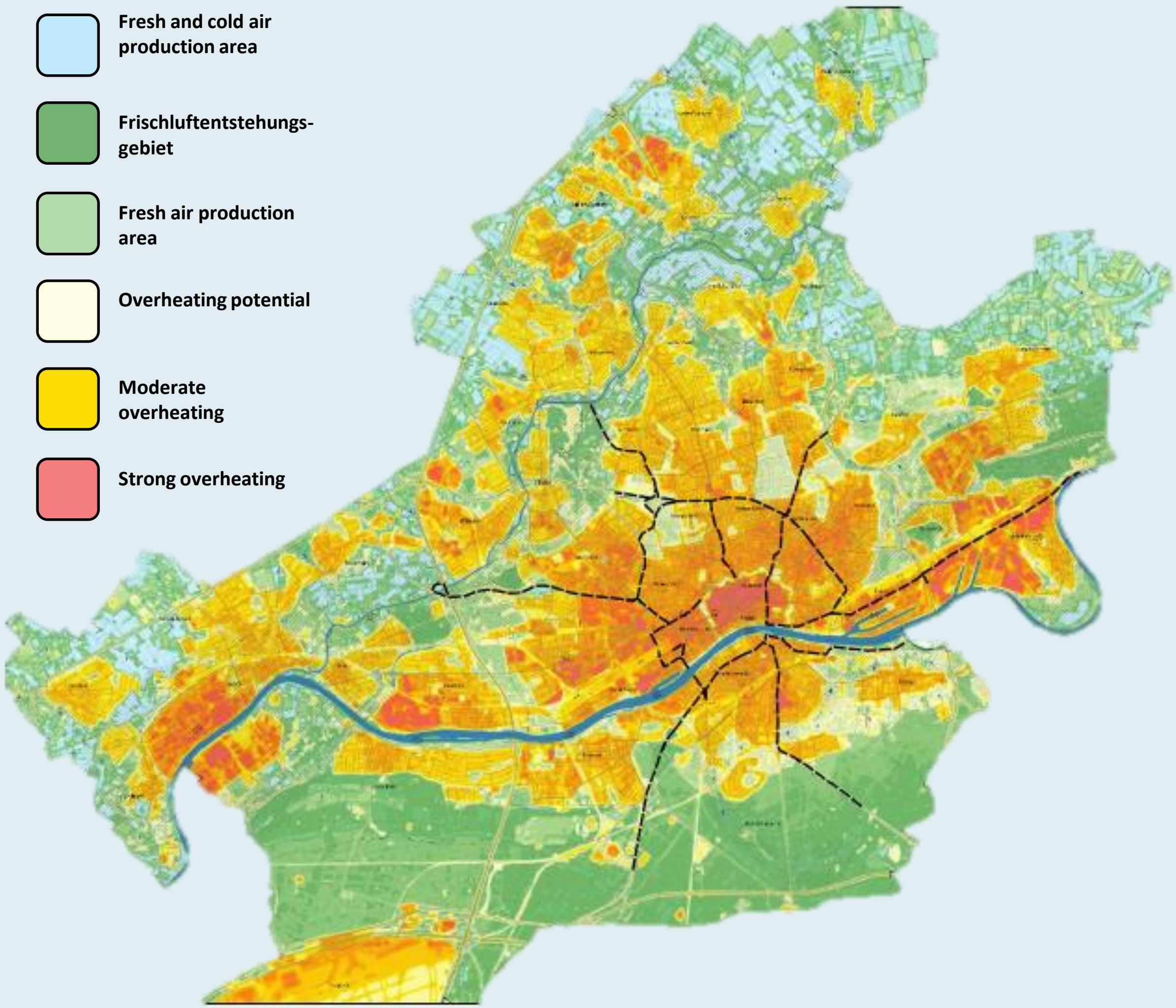
Citizens as well as public authorities are committed and successfully active in order to further improve the city climate

The Frankfurt Office of Real Estate oversees rainwater collection projects and building greening at municipal properties, and even Frankfurt's transport associations have started greening their bus stops. Advertising pillars are being given the "Frankfurt hood", a disc top with sedum planting, which serve primarily as stepping stone biotopes for insects.

That being said, there are currently (2021) about a dozen citizen's initiatives that are either protecting existing green space from destruction or successfully launching the planting of flower beds, "urban gardening", parking lot greening and more with energy and momentum.

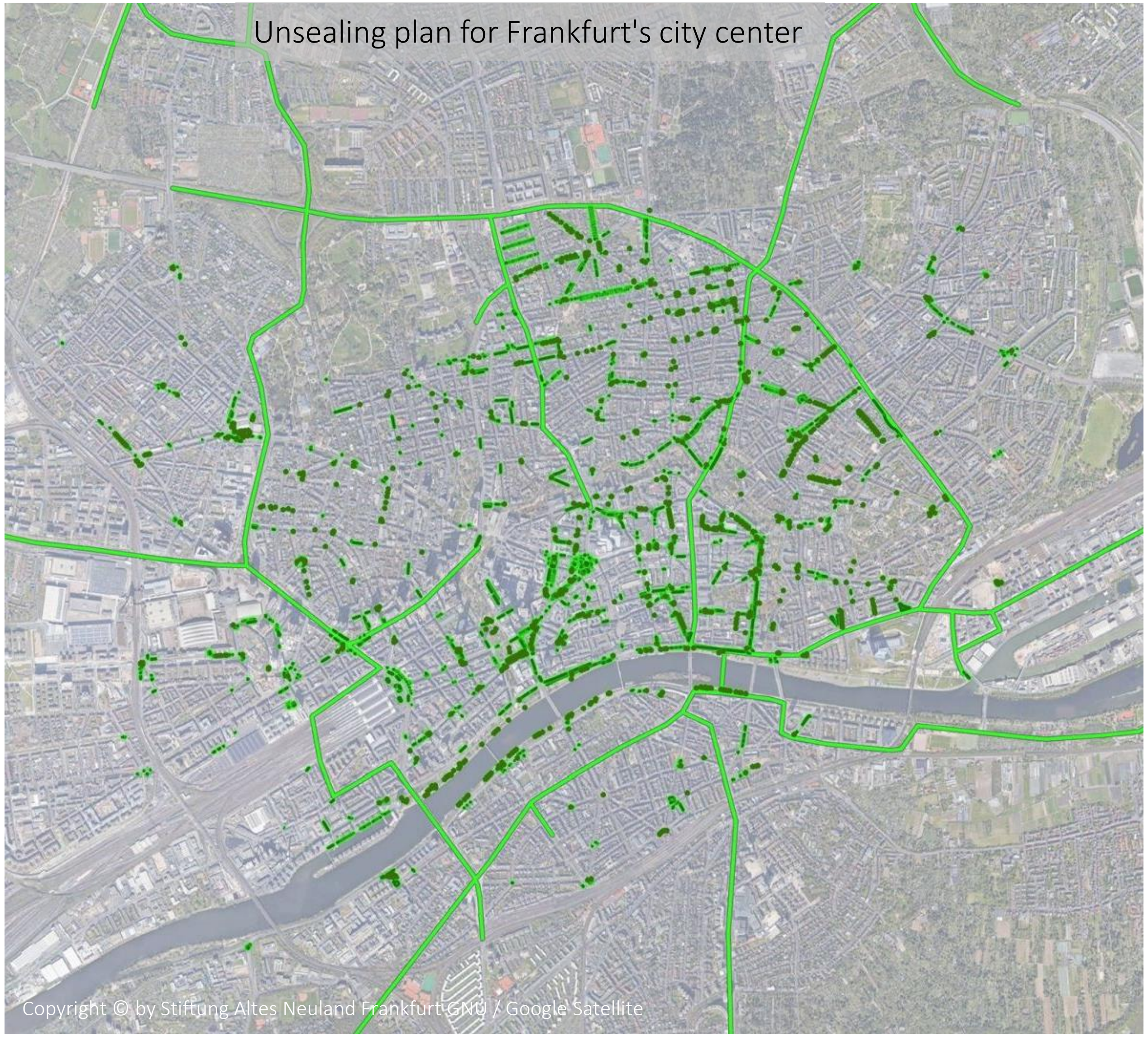
The unsealing and greening plan, which can be implemented with the help of Frankfurt Bridges, fits perfectly into this trend of the city and its citizen activities.

The bridges criss-cross parts of the city like a net and can thus send water to widely distributed green areas



Because even if there are rainy summers like 2021: Once plants have been planted, their survival must be ensured in the long term - otherwise the effort will be great after only one dry period, when most of the greenery dies, has to be disposed of and then replanted.

The water system of the Frankfurt bridges enables unsealing and greening as well as the planting of new trees on a large scale



But not only the new greenery can be watered with it: Existing urban greenery can also be vitalised and protected from withering away.

More than 40,000 square metres of land can be unsealed and greened, and around 1,000 additional trees can be planted.

This is because even undeveloped but sealed open spaces, such as Frankfurt's Hauptwache, urgently need additional shading in the hot summer months. Trees that thin out in winter and let the sun through are best suited for this purpose.

Despite all the zeal to plant as many trees as possible in the city, it is important to know, especially when it comes to urban greenery: Not all trees are created equal

Not all trees are the same, and not all greenery is the same: When selecting urban greenery, a number of things must be taken into account with regard to the local climate - otherwise the effort is in vain or even counterproductive. Although practically all trees provide welcome cooling on hot days through shading and transpiration, if they are arranged too densely, especially large-crowned street trees whose canopy closes over the middle of the street, there is an increased risk of air pollutants accumulating in such avenues.

Another problem is posed by reactive trace gases such as isoprene, which are emitted by some tree species. This can lead to the formation of ozone in combination with car exhaust gases during high solar radiation. Elevated ozone concentrations in the human habitat are considered hazardous to health because they can cause respiratory diseases. Therefore, the selection of trees should always take into account health-relevant contexts.

If trees are planted in the course of unsealing, very specific parameters must be taken into account

In the city, the most important aim of planting trees is to cool the climate by casting shade - because their contribution to cooling through evaporation takes place in the canopy, and is therefore usually much higher than the walking height of pedestrians.

In order to maximise shade, trees should be chosen that can form as large a canopy as possible - if the site allows. The size of the tree crown is more important for the cooling effect of the shade than the density of the tree crown. The selection of the tree species is an important factor for the cooling effect from this aspect alone.

Trees with very dense canopies should only be planted free-standing or at large distances from each other anyway. Often, however, the exact opposite happens: In the city, trees are often planted as tree avenues along busy streets in urban canyons. There, they often represent an obstacle to air circulation due to the "tunnel effect", which is exacerbated by dense tree crowns.

Besides the choice of the right tree species, the respective location is therefore also of great importance. Isolated positions or arrangements at distances of 20 m or more are good for the tree and also for its surroundings.

Densely planted trees generally have poorer filtering properties than loosely planted trees, through which the wind can blow more easily.

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Conclusion: Frankfurt's bridges can help to positively influence the urban climate through unsealing

Frankfurt's inner city is identified in the Climate Plan Atlas as an urban climate problem zone. This is due to the high volume of traffic, high building density and, above all, the lower proportion of green spaces and higher degree of sealing, which results in increased heat stress in summer.

The Frankfurt bridges provide a remedy for this urban climate-relevant factor with the help of their irrigation network: Inner city areas can be unsealed and greened.

Trees in the city centre, in particular, can have a cooling effect through the shade they cast, but they must not be planted in too dense an arrangement so that air exchange is guaranteed.

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The goal: to arm the city against drought and floods


The green metropolis of the future


Vitalization of the urban green

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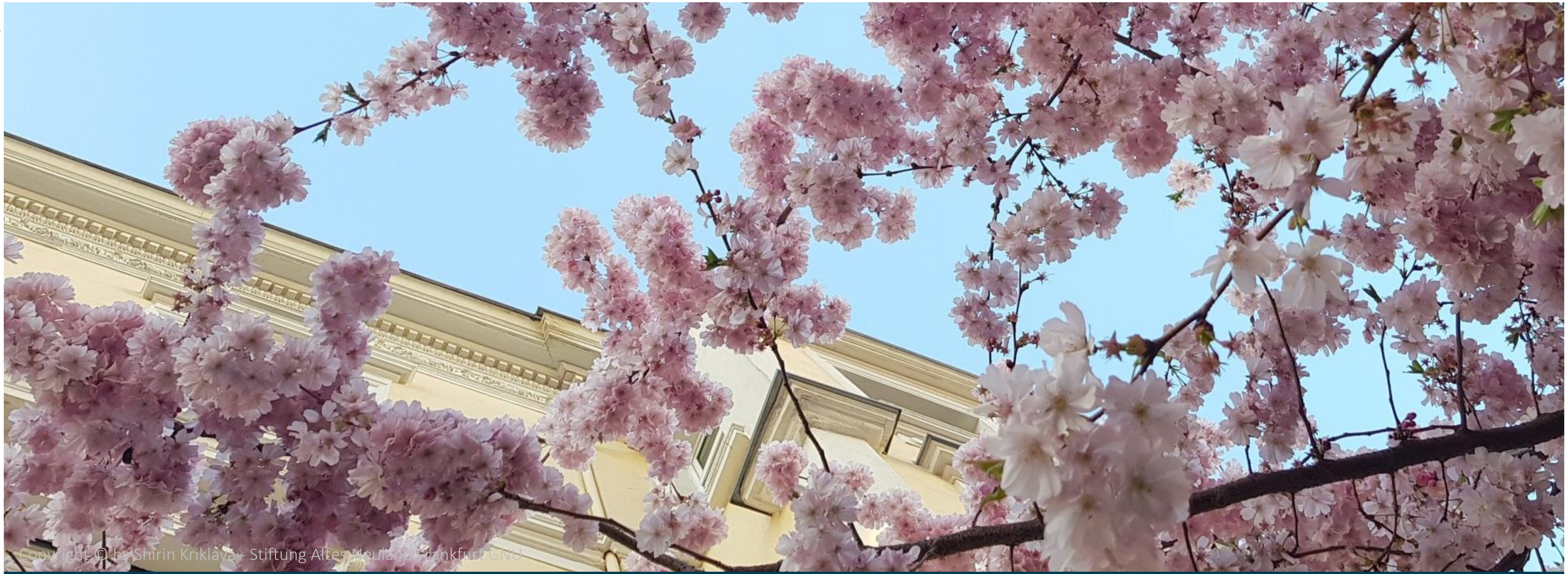
Effects of the bridges



Effects of the bridges on the city climate

In micro-scale terms, Frankfurt's bridges have a positive effect on the urban climate: The shade cast by the bridge corpus noticeably lowers the perceived temperature in the street space below, making it pleasantly cool there on hot summer days. Bridge buildings and medium-high planting also provide pleasant shade on the bridge corpus. At the same time, due to their columnar character, the Frankfurt bridges represent only a minor obstacle to air flow, thus maintaining the ventilation of the street space. Furthermore, it can be assumed that the bridges will not cause a significant increase in the immission load: The predicted decrease in traffic-related air pollutants by the time the project is completed will benefit the Frankfurt bridges. This is because the number of e-cars and hydrogen trucks will increase significantly in the coming decades and replace the pollutant-emitting combustion engines.

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Content: The thermal and dynamic impact of Frankfurt's bridges is analysed exemplarily on a study area in the city centre with the help of computer simulations

The section of Mainzer Landstraße starting from Platz der Republik was chosen as the study area, as this was identified as the potential "worst case passage" of the Frankfurt bridges.

The thermal conditions with regard to temperature and local flow behaviour were analysed as they appear on a hot summer day in the ACTUAL versus PLAN condition. Furthermore, the wind dynamic effects of the Frankfurt bridges were simulated in the same study area, with an average cloudy day as the meteorological starting position, on which a common superordinate wind system comes into play. Several inflow directions were considered.

Potential effects of the bridge construction on pollutant accumulation under the bridges were not analysed, as a significant decrease of pollutants in the road space can be expected anyway until the completion of the bridge construction due to the expected rapid increase of emission-free e-cars and hydrogen trucks.

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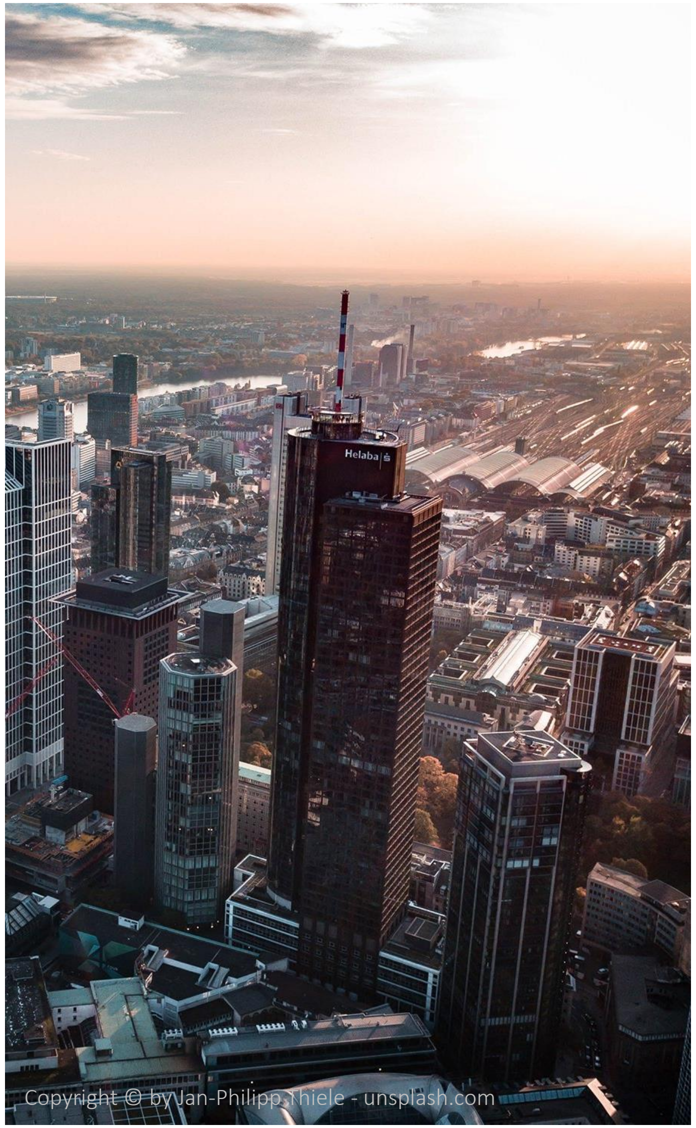
With a total surface area of only two square kilometres, the Frankfurt bridges do not influence the climate of the 250 square kilometre city of Frankfurt on a mesoscale, but only on a microscale

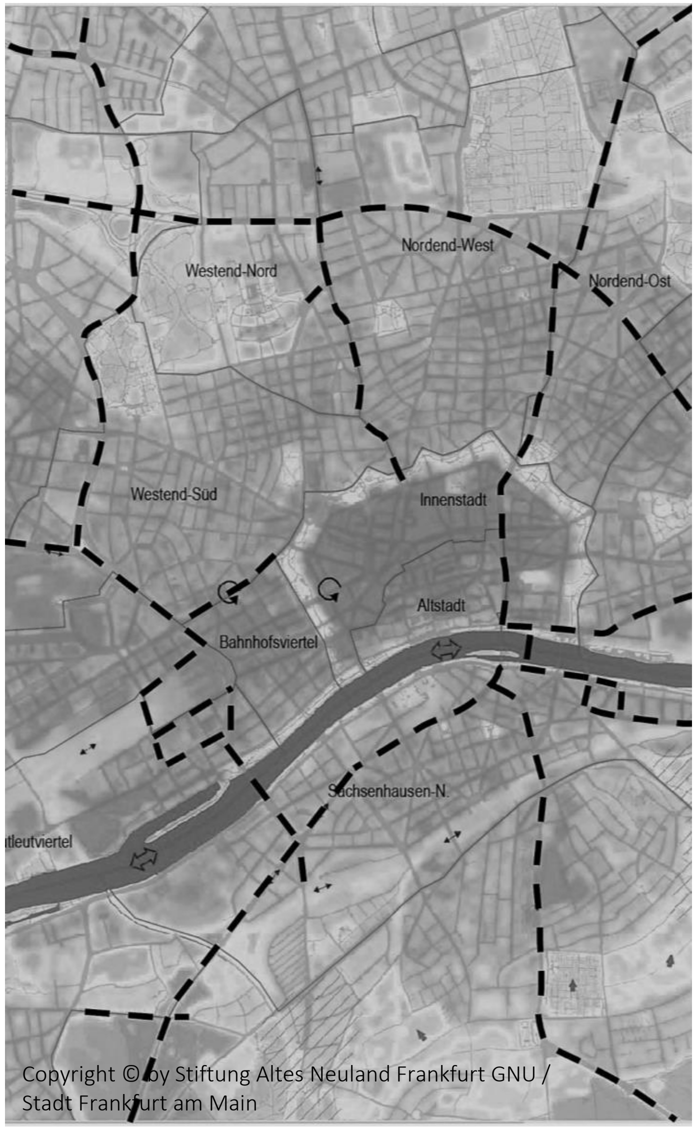


Since Frankfurt's bridges only criss-cross the city like a fine network, they have no influence on the city's climate on a large scale.

In certain road sections, however, their impact on the surrounding area can be predicted by simulations.

As with any structure, the most relevant thermal factors are shadows cast and the interference with or alteration of wind currents.

In terms of pollutant loading, like any structure, they restrict large-scale air exchange; however, because they provide a second level of traffic that relieves congestion on the streets below them, this must also be considered in the final evaluation.



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The climatic effect of the bridges is however locally quite noticeable, as a view of the surface data shows

Area city of Frankfurt: 250 km²

- of which fully sealed traffic areas: 52 km² and
- Vegetation areas: 98 km²

Vegetation areas in the bridge context: 1,5 km²

- green area created on the bridges: 1 km²
- additional upgrading of 0.2 km² directly next to the bridge
- Additional unsealed green space: 0.04 km² in the FFM urban area
- additional vitalised green area in the urban area through bridge irrigation: 0.2 km²
- additional trees planted in the inner city area: 1,000 trees

Accordingly, the Frankfurt bridges indirectly do a lot of good for the city climate locally: by reducing road traffic, watering green spaces and trees throughout the inner city area, and as an alternative to the usual sealing of open spaces as a result of the increasing demand for housing

In order to identify the neuralgic points at which the bridges in Frankfurt pass, the Frankfurt Climate Plan Atlas and the Rhine-Main Air Quality Control Plan were used as a basis

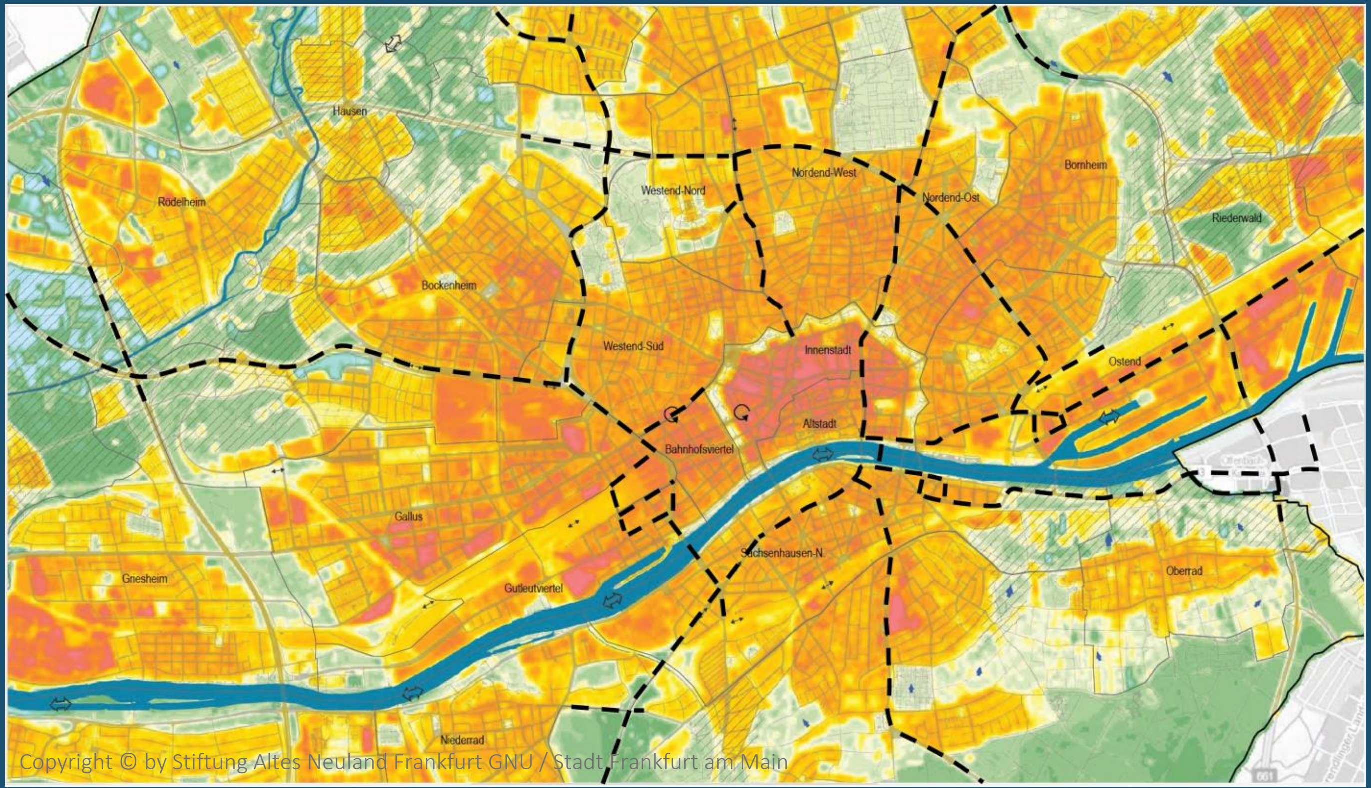
The thermal situation of a city is usually depicted in so-called "climate function maps". For Frankfurt, such a map can be found in the "Klimaplanatlas Frankfurt", which the city had prepared in 2016.

German cities have the immission pollution of the air by nitrogen oxides and particulate matter determined for their region within the framework of the so-called "Clean Air Plan". Frankfurt's situation is currently recorded in the Clean Air Plan Rhine-Main 2020.

Along the course of the bridges, these maps can be used to determine which road sections may tend to aggravate the stress situation and should therefore be the focus of simulations that show or forecast the influence of the bridges on the urban climate; conversely, potential for improvement can also be identified for these sections.

Thermal load and pollutant load are highest in the inner city - (1) Thermal load

The climate plan atlas shows which urban areas tend to overheat in summer, making it too hot and/or too oppressive for people to live there. Excerpt from the Frankfurt Climate Atlas: The darker the red, the more overheated the area.



- Fresh and cold air production area
- Fresh air production area
- Mixed and transitional climates
- Overheating potential
- Moderate overheating
- Strong overheating

Detailed legend of the climate plan atlas

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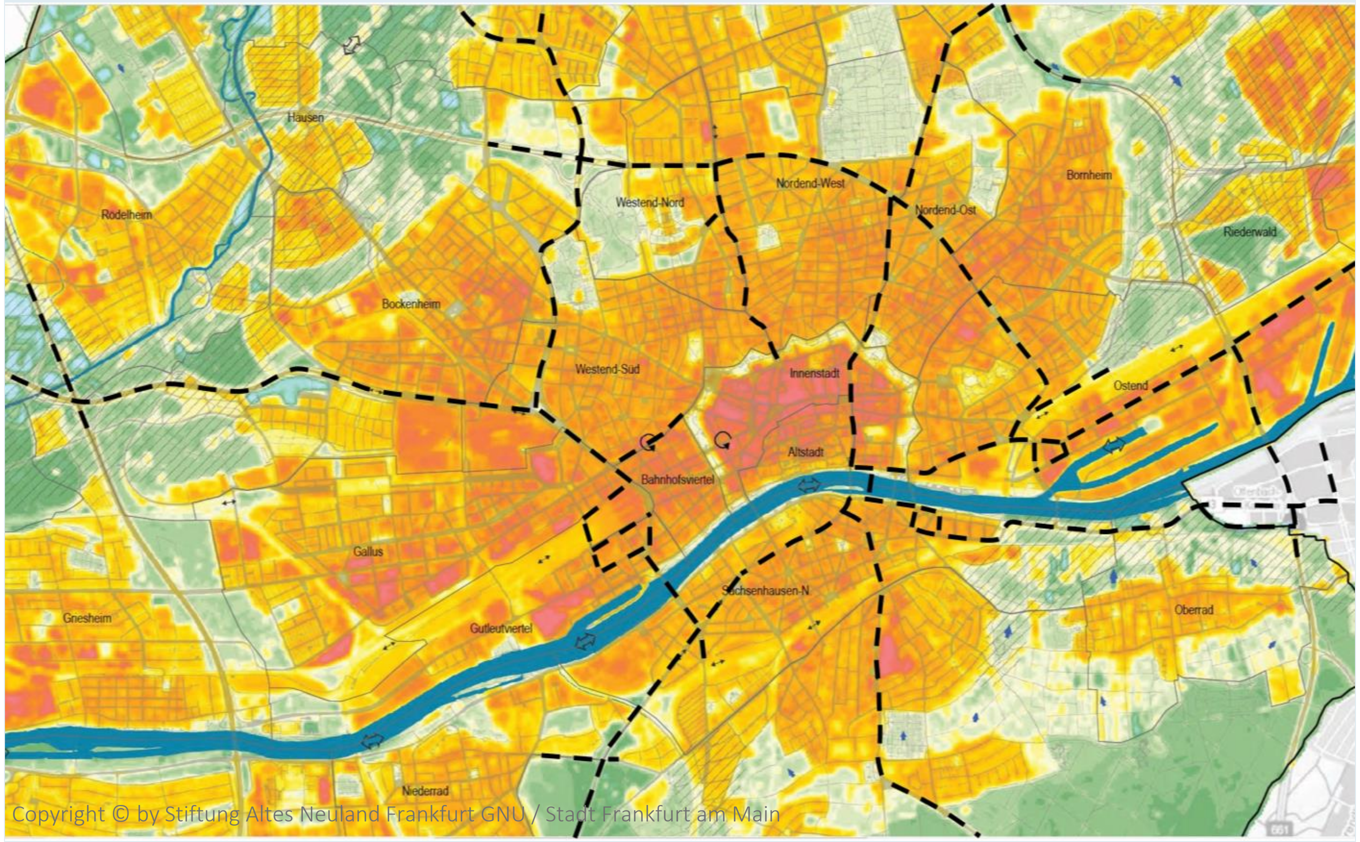

	Fresh and cold air production area	Orientation according to VDI Climate property: Open-air climate. Highly active, mainly cold-air-producing surfaces in the Outdoor area - Mostly with low roughness and corresponding slope inclination.
	Fresh air production area	Orientation according to VDI Climate property: Forest climate. Areas without emission sources; mainly with dense tree cover tree population and high filtering effect.
	Mixed and transitional climates	Orientation according to VDI Climate property: Climate inside urban green spaces. Areas with a very high proportion of vegetation, low and discontinuous emissions; Buffer areas between different climatopes.
	Overheating potential	Orientation according to VDI Climate property: Suburban climate. Built-up areas with sealed surfaces, but with a lot of vegetation in the open spaces, adequate ventilation.
	Moderate overheating	Orientation according to VDI Climate property: urban climate. Dense development, high degree of sealing and little vegetation in the vegetation in the open spaces; ventilation deficits.
	Strong overheating	Orientation according to VDI Climate property: Inner city climate. Highly dense inner city areas/city, industrial and commercial areas with little industrial and commercial areas with little vegetation and a lack of ventilation.

	Wetterau wind	The Wetterau wind is a regional nocturnal flow from the northeast at night. It flows over the the central urban area of Frankfurt and acts as an important east and west of the city centre and reaches down to the east and west of the city centre. During the day, the wind direction direction reverses to the southwest in accordance with the leading the Taunus ridge to the southwest.
	Air duct	Due to orientation, surface characteristics and width preferred surface for the transport of air masses transport. Air flow paths are characterised by low roughness (no tall buildings, only single trees) characterised by low roughness.
	Direction of action Air conduction path	They enable the exchange of air masses between the surrounding countryside and the city. Their effectiveness depends on the wind distribution. In addition, air ducts can be of great of great importance for climatic relief, especially in climatic relief, especially in low wind conditions.
	Cold air path - Cold air flow direction	Thermal wind system induced during the night(downslope wind). The cold air generated on the slope near the ground flows down the slope. The arrow symbol corresponds to the direction of flow.
	Ventilation - aeration pathway	In addition to air guideways, also railway tracks, wide roads, river courses etc. that act as additional airways. Canalisation of air flows.
	Wind field change	Disturbance of the wind field caused by high buildings. Indication of increased turbulent wind velocity (gustiness) and drastic changes in wind direction (vortex formation, flow around).

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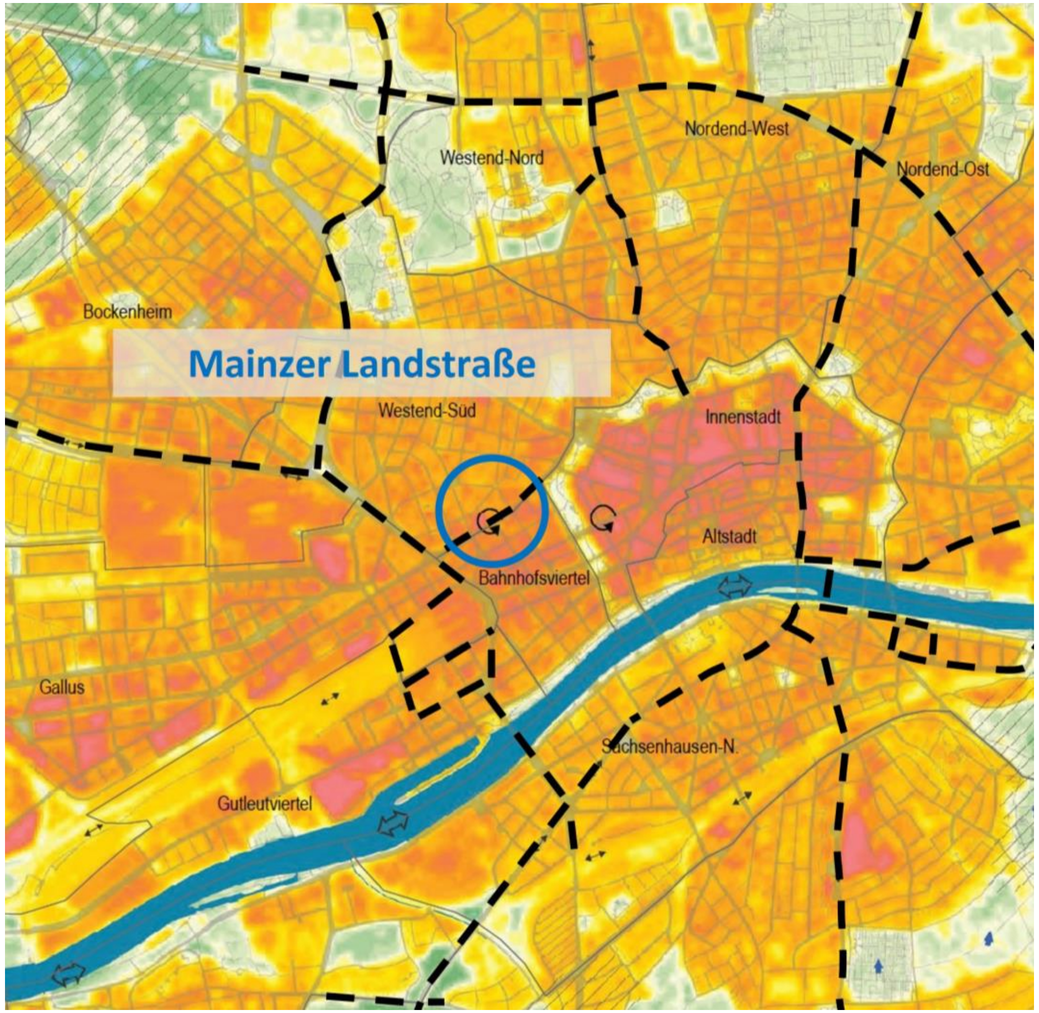
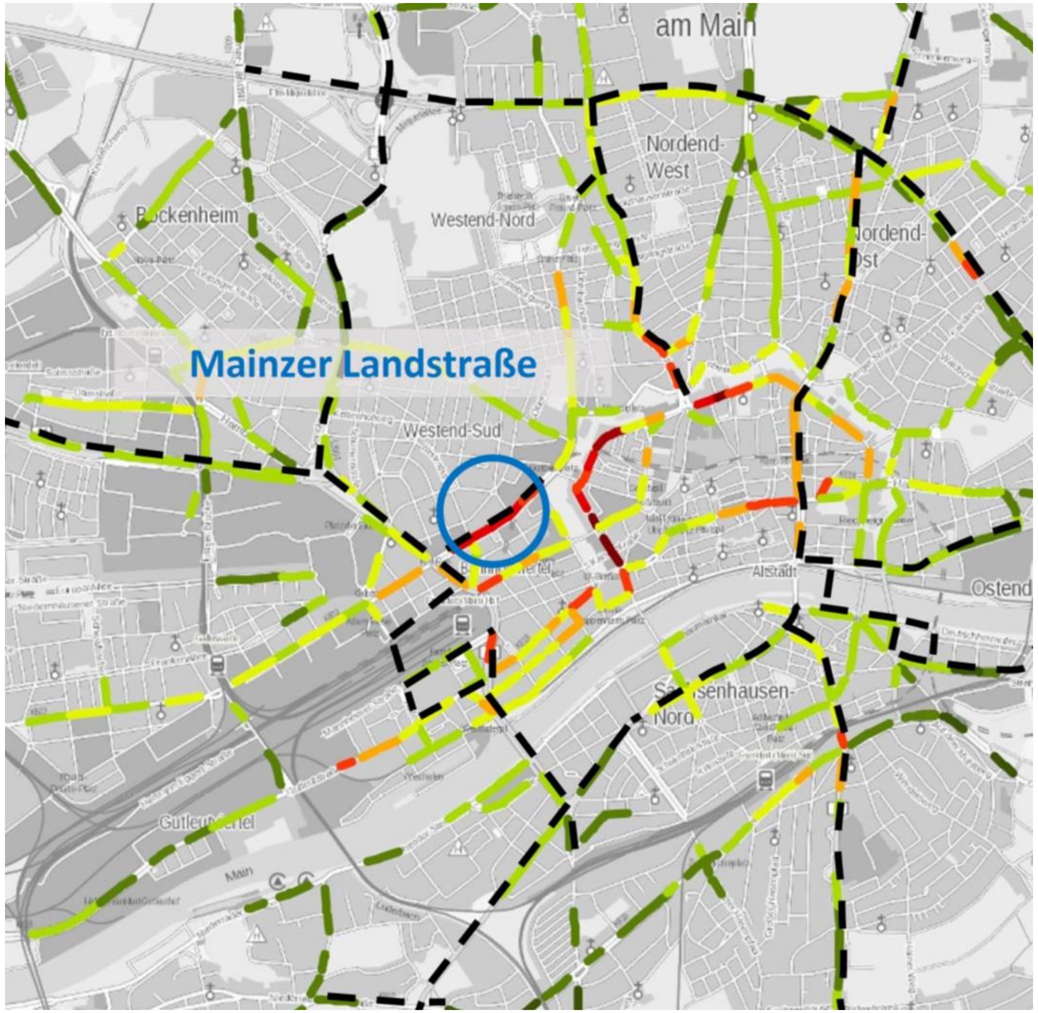
Thermal load and pollutant load are highest in the inner city - (2) Pollutant load

The nitrogen measurement plan along Frankfurt's major traffic axes is a good indicator of the overall traffic-related pollutant load in the respective urban areas.

The map section from the nitrogen oxide analysis of the LRP Frankfurt shows in red areas with the highest pollution.

If one compares the neuralgic areas on both plans, there is an exemplary location on Mainzer Landstraße that is critical in both plans





The characteristics of the study area already suggest that it is problematic in terms of urban climate

Characteristics of the Mainzer Landstraße

- The Republic Square is a large traffic area.
- the Mainzer Landstrasse leading to it lies partly in a high-rise canyon with.
- Wide street canyon with parking on both sides
- High degree of sealing by asphalt and paving stones, hardly any vegetation and open spaces
- Mainly office buildings
- Closed, very high building complexes
- Four-lane road
- High pollutant and heat emissions due to high traffic volume (39,000 vehicles/24h)
- High NO_2 concentration of 46 µg/m³ (forecast from LRP for 2021)

Other potentially critical modelling areas

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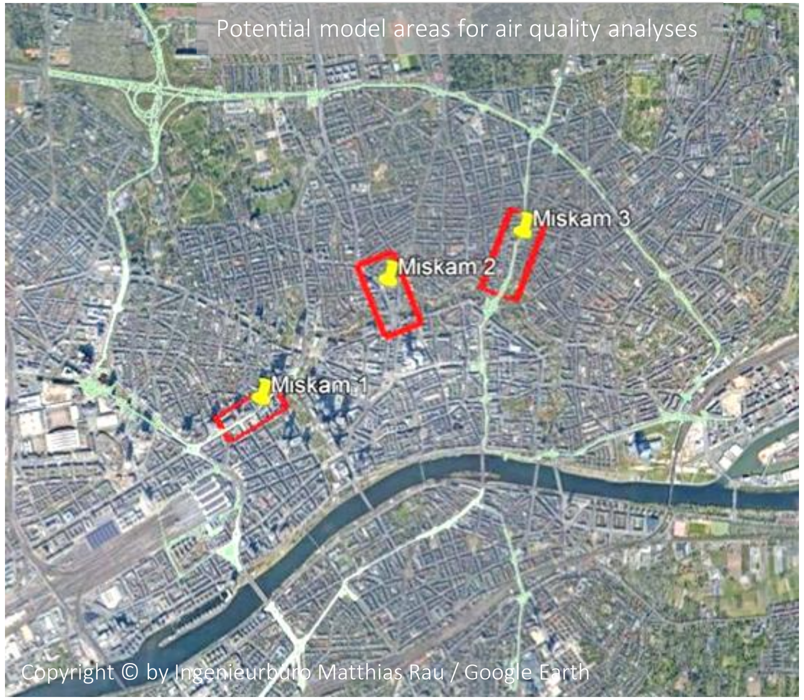
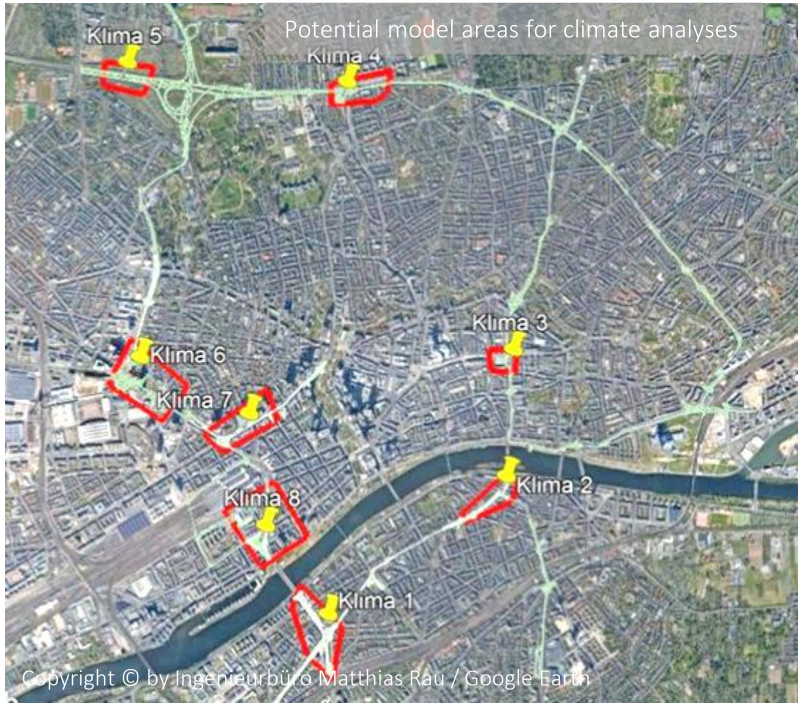
For both an exemplary air hygiene analysis and an exemplary climate analysis, further neuralgic points in Frankfurt have been identified which are already critical along the bridge route.





But in order to examine in principle whether the structural concept of the bridges with their dimensions, surfaces, plantings, etc. tends to have a positive or negative effect, the first step was to target the section from Platz der Republik to Mainzer Landstraße as a worst-case example.

At all less critical locations in Frankfurt, the effects are likely to be correspondingly smaller.

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Content of the urban climatic analysis: How will the thermal and wind dynamic conditions along Mainzer Landstraße towards Platz der Republik change due to the construction of the Frankfurt bridges?

The effect of the bridge body, including the buildings as well as the new greenery (on and next to the bridges) has been investigated with regard to thermal load and wind comfort. The following questions were taken as a basis:

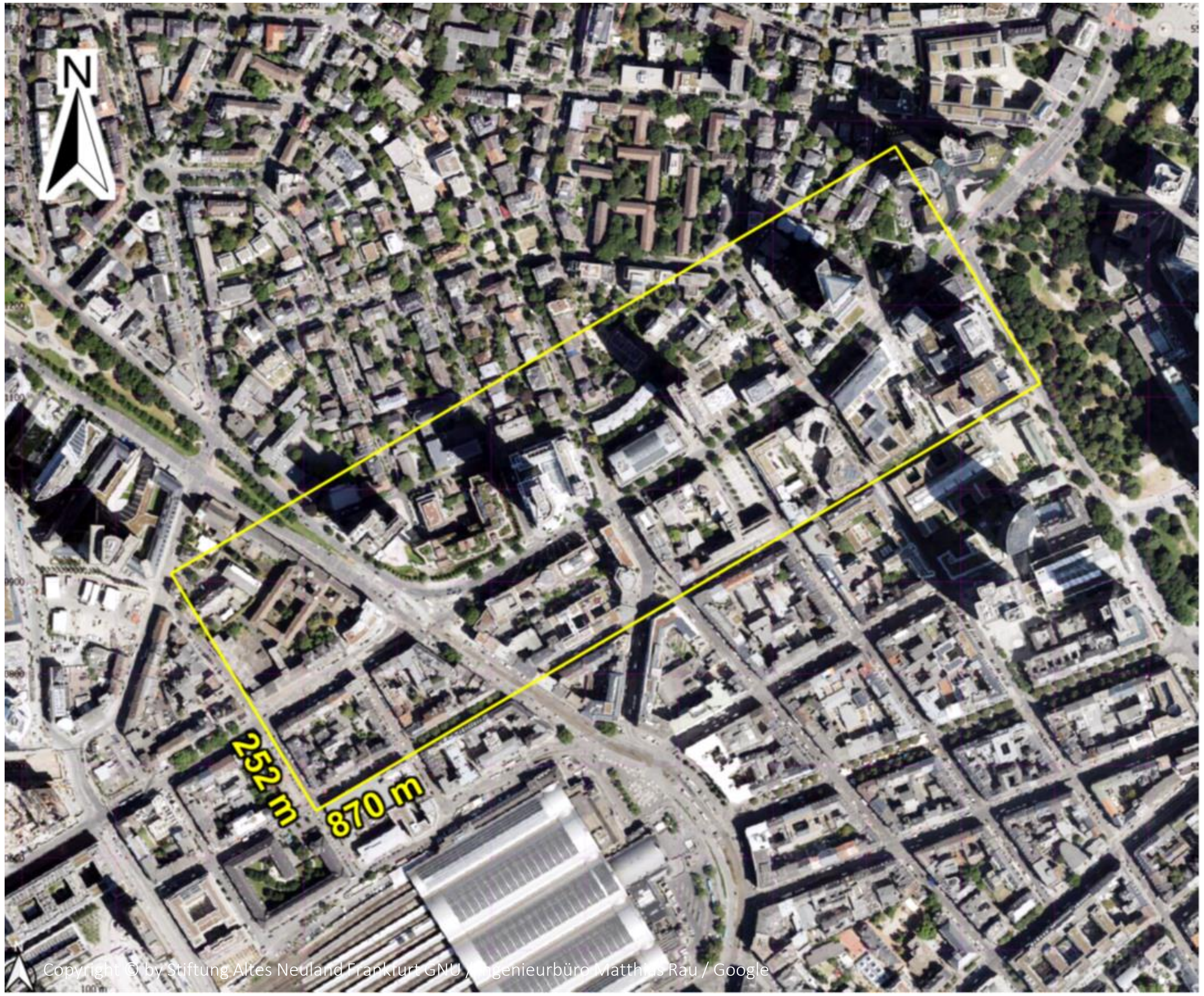
What is the benefit in terms of thermal conditions of a bridge compared to the current situation?

How do the parameters PET (physiologically equivalent temperature) and wind speed change in the street space or in the area of the nearest buildings?

Which fluid dynamic effects and modifications of the wind field are caused by the bridge?

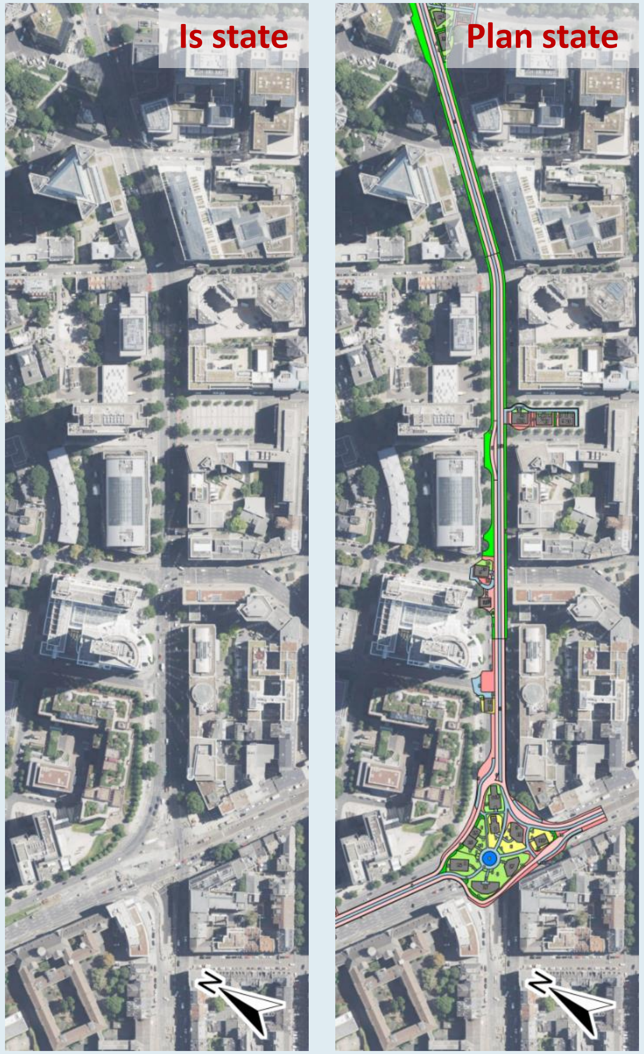
How far does the thermal and wind dynamic influence of the bridge extend laterally into the development?

When delineating the study area for the effects of the bridge construction, the adjacent areas must also be taken into account



Due to the spatially limited influence of the Frankfurt bridges, the model area was defined to include the neuralgic section of the Mainzer Landstraße from the Taunusanlage to the Platz der Republik. In addition, the area extends a good 100 metres into the surrounding buildings in order to be able to record all climatic effects of the Frankfurt bridges on their vicinity.

Two simulation runs were made for each of the two model-based analyses



In order to determine the effects of the Frankfurt bridges on the urban climate, two simulation runs each were carried out for both the thermal and the dynamic analysis.

In the first run, the current atmospheric condition along Mainzer Landstraße was simulated without the planned bridge construction (zero case).

In the second model run, the data set was supplemented by the construction of the corresponding bridge section (plan case).

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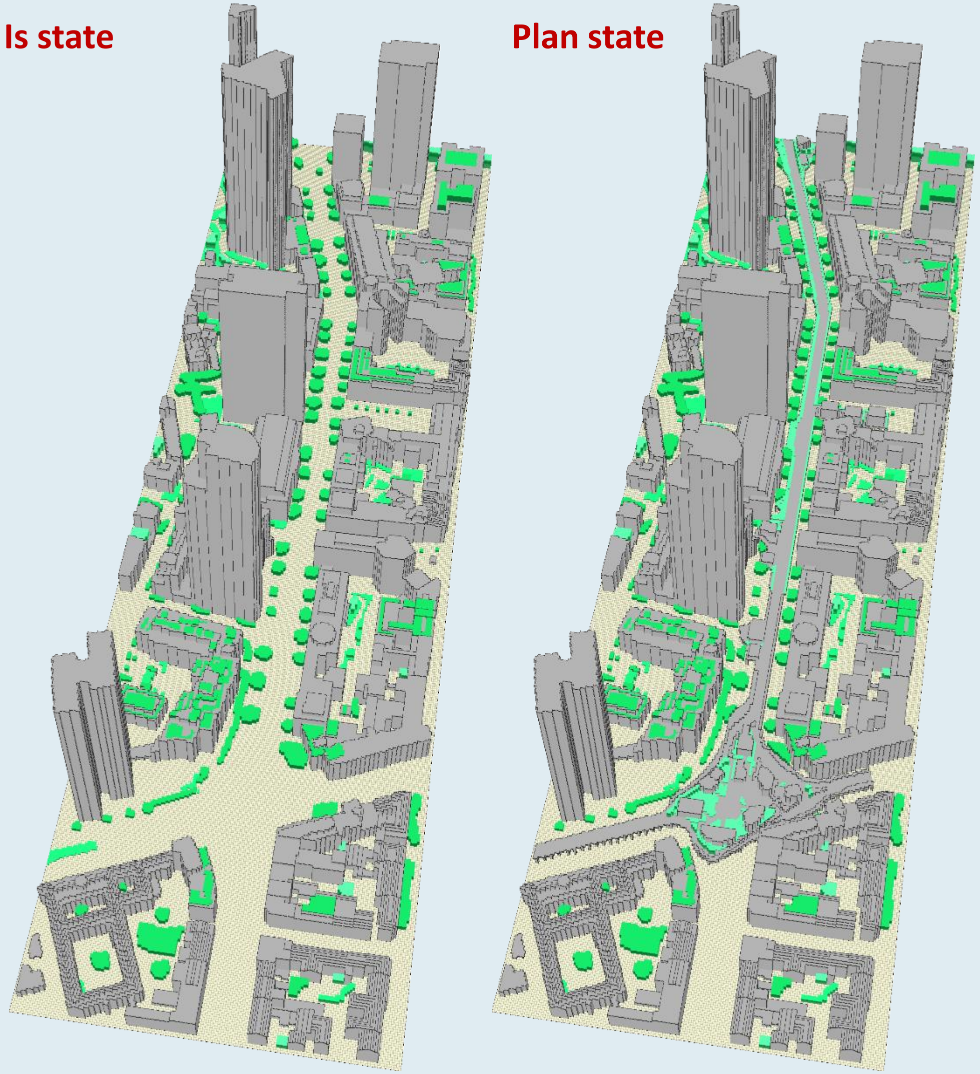
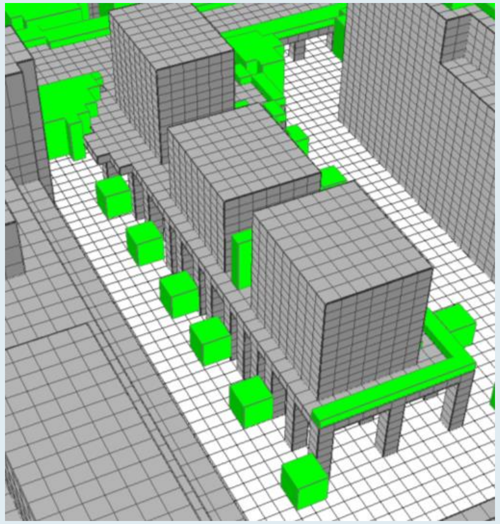
The basis for the simulation was a detailed model of the bridge section and the road with the existing buildings



Due to the selected resolution of 1 to 1.5 m, the cubatures of the Frankfurt bridges, the buildings as well as the vegetation can be reproduced very accurately by the model, as can be seen here in the example of the "Envimet" model used.

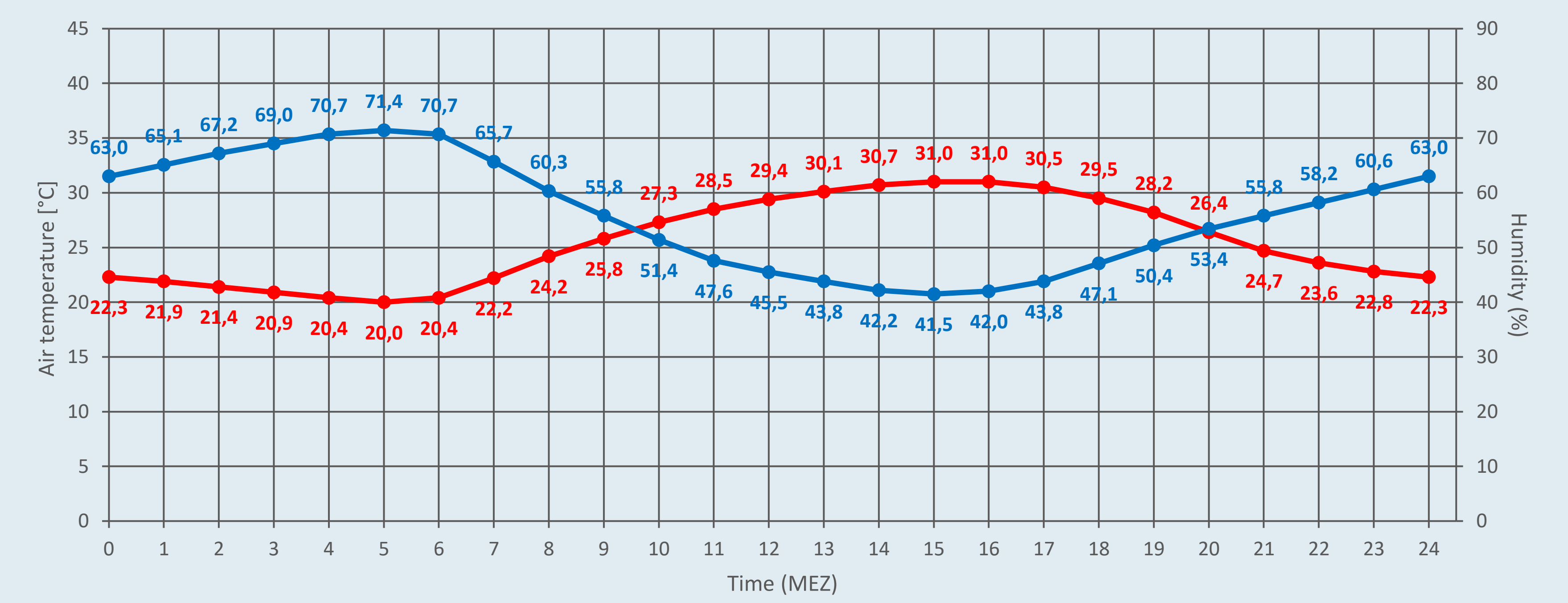
This high degree of accuracy is of decisive importance for the results, because the better the spatial resolution of the model, the more realistic the results.



Thermal analysis: The thermal situation was simulated under the meteorological conditions of a hot summer day preceded by a tropical night

In this weather scenario, daytime highs exceed 30° C, while skies are cloudless and overhead winds are light. At night, temperatures do not drop below 20° C.

In temperate latitudes, such hot days are particularly frequent in July and August. Outdoor swimming pools and ice cream parlours are very popular - and shady areas are increasingly sought out.

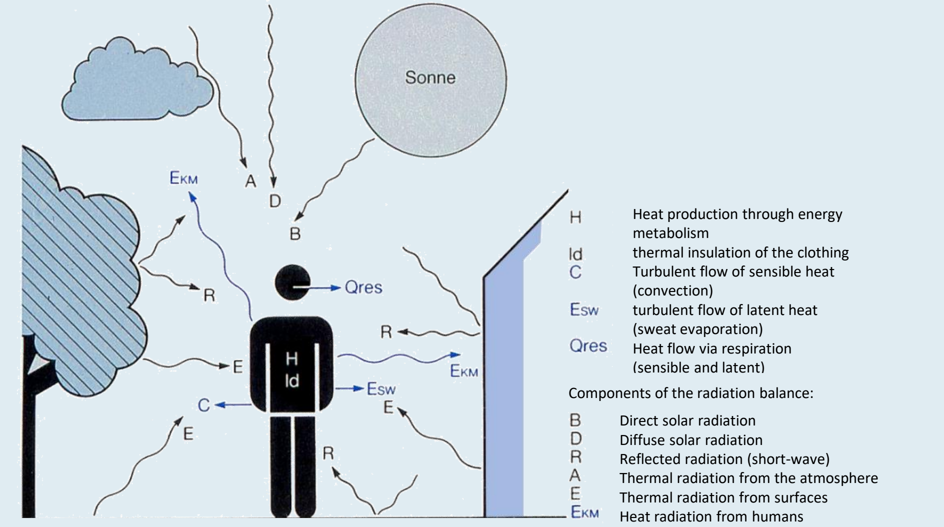


In order to illustrate how people feel thermally under such weather conditions - without or with the Frankfurt bridges - the "physiologically equivalent temperature" (PET) is used

The PET is a measure of thermal comfort that - unlike the measured air temperature, for example - provides information about how comfortable or uncomfortable certain weather conditions feel for the human body.

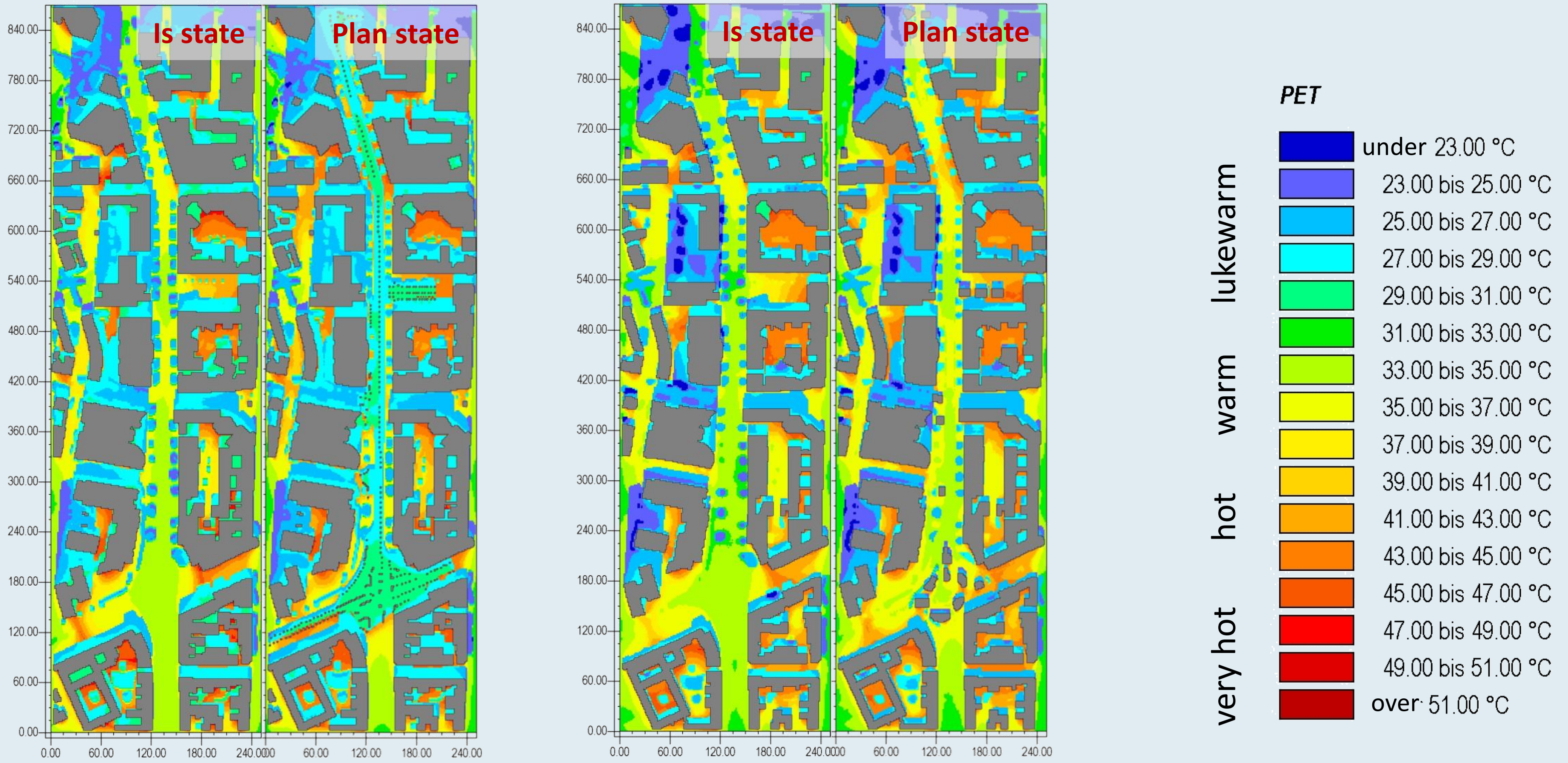
Similar to the perceived air temperature, influencing factors such as humidity (sultriness), wind speed (sweat evaporation), heat radiation from the environment (buildings, road surfaces) and solar radiation (albedo effect, sunstroke) are taken into account for this purpose.

PET / °C	thermal sensation	load level	physiological effect
	very cold	extreme stress	cold stress
4	cold	heavy load	
8	cool	moderate load	cooling stimulus
13	slightly cool	weak load	
18	cosy	no load	
23	slightly warm	Weak load	thermal stimulus
29	warm	Moderate load	
35	hot	Heavy load	heat stress
41	very hot	Extreme load	



The thermal effect complex (according to Jendritzky)

The effects that the Frankfurt bridges have on the characteristics of the PET can be seen in principle from a direct comparison of the model results of the zero and plan cases



PET at 2 m above ground without (left) and with bridge structure (right)

PET at 10 m above ground without (left) and with bridge structure (right)

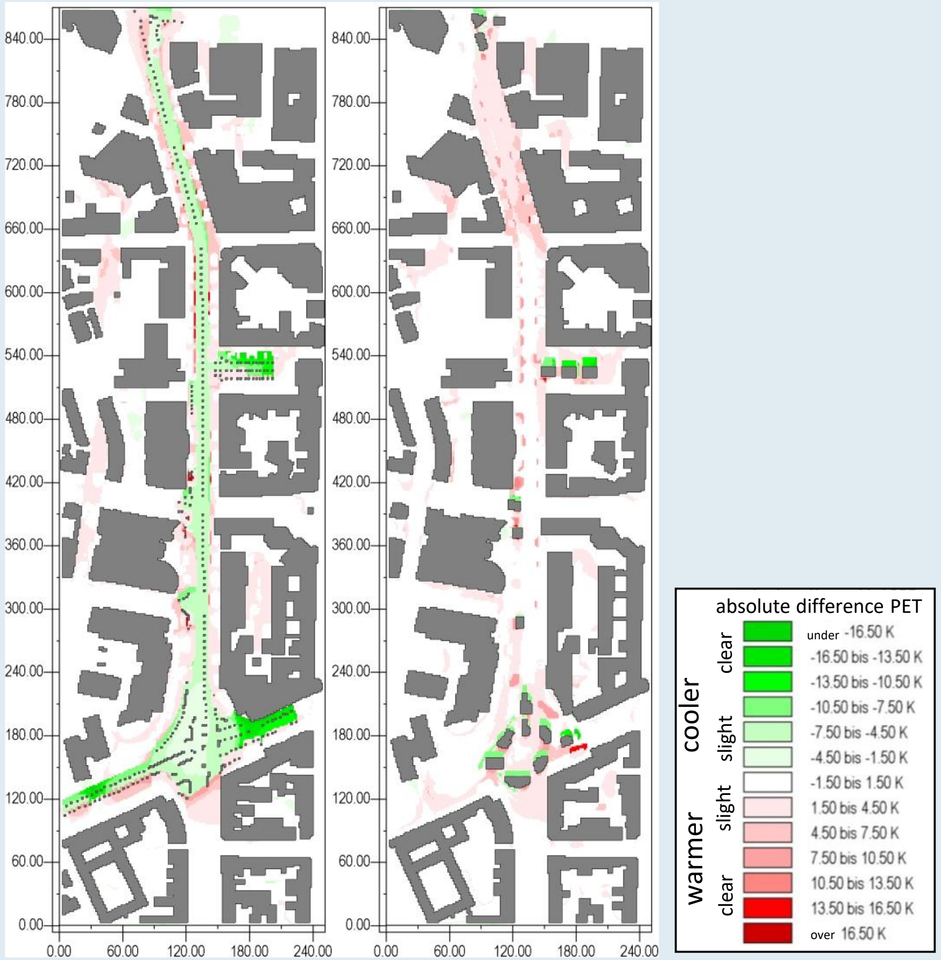
The comparison shows: Without the shady bridge, the PET rises up to 37 degrees on a hot summer day - with the bridge, however, it is only 27 to 29 degrees

The situation is shown at 3 p.m. (summer time), when the highest daytime temperatures prevail and the thermal load tends to be greatest. The height level 2 m above ground describes the conditions in the lower level of Mainzer Landstraße; the level 10 m above ground corresponds to a height of 2 m above the bridge deck.

In the area close to the ground, the temperature deviations can be seen very easily: Without the shady bridge structure, the PET in the Mainzer Landstraße area reaches peak values of 35 or even 37 °C almost everywhere, while the temperatures there are often only between 27 and 29 °C with the bridge corpus in place.

When comparing the PET on the bridge plate, however, the differences are not immediately obvious. This requires a different form of representation...

The PET differences between the actual and the planned state can best be shown by means of so-called "difference maps"



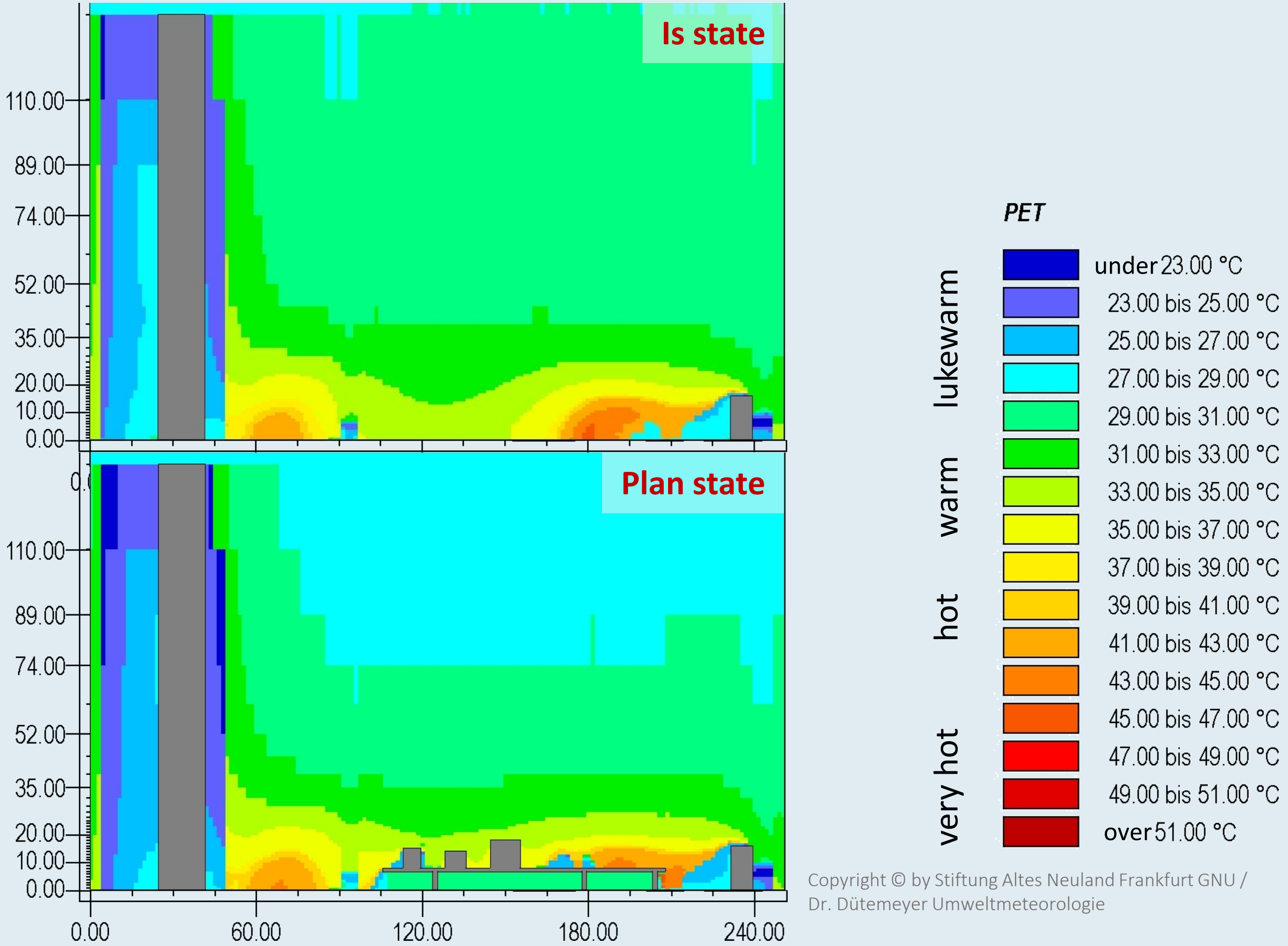
Difference of PET
in 2 m over ground (left), 10 m above ground (right)

Since the changes in PET are spatially limited and occur to a rather small extent, especially on the bridge deck, they are best shown with the aid of difference maps in which the differences between the simulation runs of the zero and plan cases are highlighted in colour.

The influence of the Frankfurt bridges on the PET is particularly evident at 2 m above ground, i.e. at the street level of Mainzer Landstraße: The shading of the lower level results in a lowering of the PET by 5 to 7 K. The shading of the lower level results in a lowering of the PET by 5 to 7 K. Since a deviation of more than 6 K in principle results in a new comfort level, the cooling caused by the shadow cast by the bridge structure is of great importance. In the vicinity of the Frankfurt bridges, on the other hand, isolated increases in PET (reddish discoloration) can be detected. However, since the temperature differences are only slightly pronounced, they have no particular relevance for thermal comfort.

At 10 m above ground, i.e. at 2 m above the bridge deck, the superstructures above Republic Square and Francois Mitterand Square result in numerous shadow zones (green). Here, too, the comfort improves by a whole step.

If you look at the PET in the cross-section of Mainzer Landstraße, the lowering of the PET under the bridge caused by shadows becomes visibly apparent. The extent to which it becomes more bearable there in summer is enormous



PET in cross-sectional view without (top) and with bridge structure (bottom)

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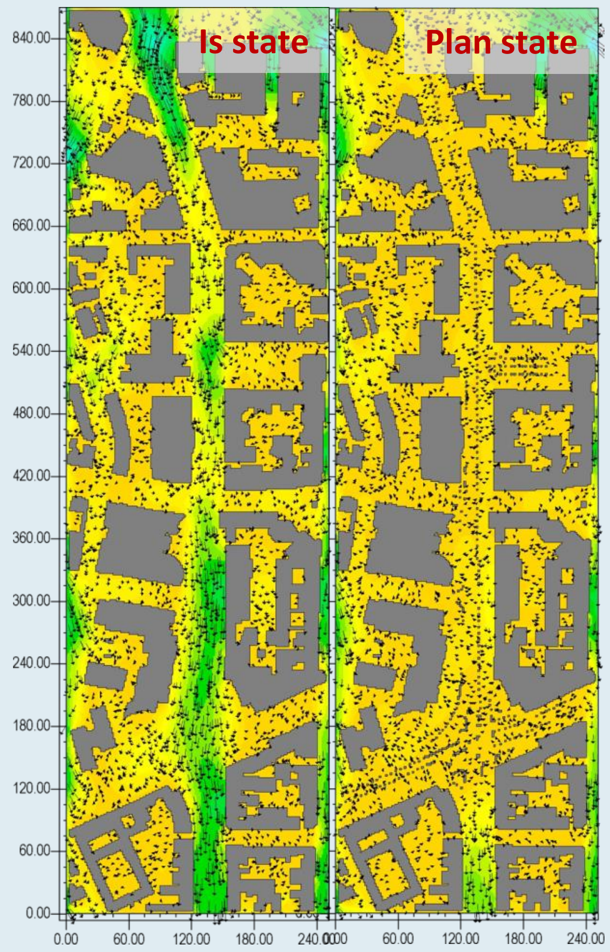
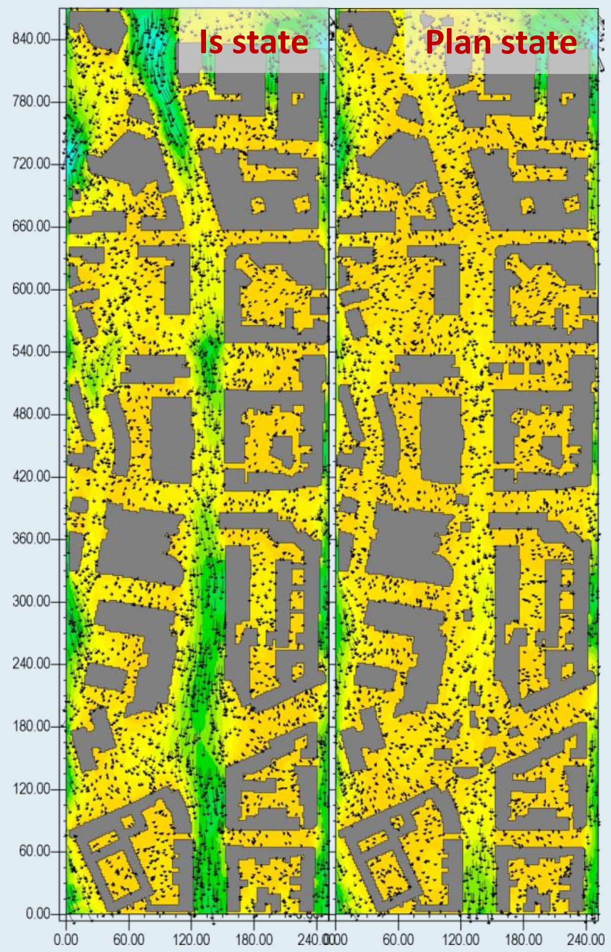
The Frankfurt bridges cause a slight modification of the thermally induced wind field



Wind speed at 2 m above ground level in the actual (left) and planned case (right)



Wind speed at 10 m above ground level in the actual (left) and planned case (right)

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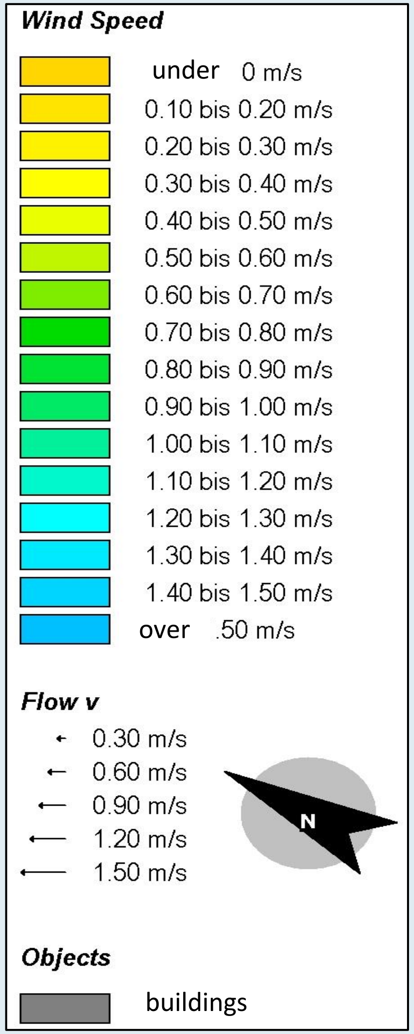

If the superordinate flow field has only low wind speeds, a thermal wind system forms in the city in summer due to temperature contrasts and the resulting pressure differences. Due to the dense building structure of Frankfurt's inner city, however, this is already very weak in the area of Mainzer Landstraße in its current state. At the hottest time of day (3 p.m.), the wind in the street area is rarely stronger than 0.8 m/s at an altitude of 2 or 10 m above ground - a gentle breeze that corresponds to wind force 1 on the 13-step Beaufort scale and is barely perceptible to people. In the inner courtyards of the peripheral buildings as well as in the cross streets leading into the city, there is practically no wind at all.

In the plan condition, the situation does not look fundamentally different both in the lower level and on the Frankfurt bridges. It is true that the wind speeds in the course of Mainzer Landstraße show a tendency towards a reduction in ventilation compared to the actual case - which is not surprising in view of the fact that the Frankfurt bridges and the additional buildings at Platz der Republik act as flow obstacles. However, it is decisive that both the absolute velocities and the reduction amounts (generally less than 0.5 m/s) are on such a low level that in no case a noticeable or physiologically relevant deterioration of the air exchange can be assumed. Of course, this is even more true for the downstream streets in the vicinity of Mainzer Landstraße, where the thermal-dynamic conditions are even less influenced.

The change in wind speed due to the construction of the bridges is so small in the study area that it is hardly perceptible to humans

Interim conclusion: From a thermal point of view, the Frankfurt bridges represent an enrichment for Frankfurt's urban climate

From a thermal point of view, the Frankfurt bridges do not lead to a significant deterioration of the current situation. On the contrary, the shadows cast by the bridges, their discreet structure and their greenery create a climatic enhancement of Mainzer Landstraße that can be transferred to all other neuralgic stretches of road.

For thermally induced wind systems, the Frankfurt bridges also represent only a minor flow obstacle, so that even in sunny weather no perceptible impairment of air exchange is to be expected.

In hot summers, Frankfurt's bridges thus create pleasantly cool comfort zones in which shading effects both underneath and on top of the bridges effectively counteract the thermal stress on citizens.

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Dynamic analysis: The dynamic situation was simulated under the meteorological conditions of a cloudy day with stronger overlying winds

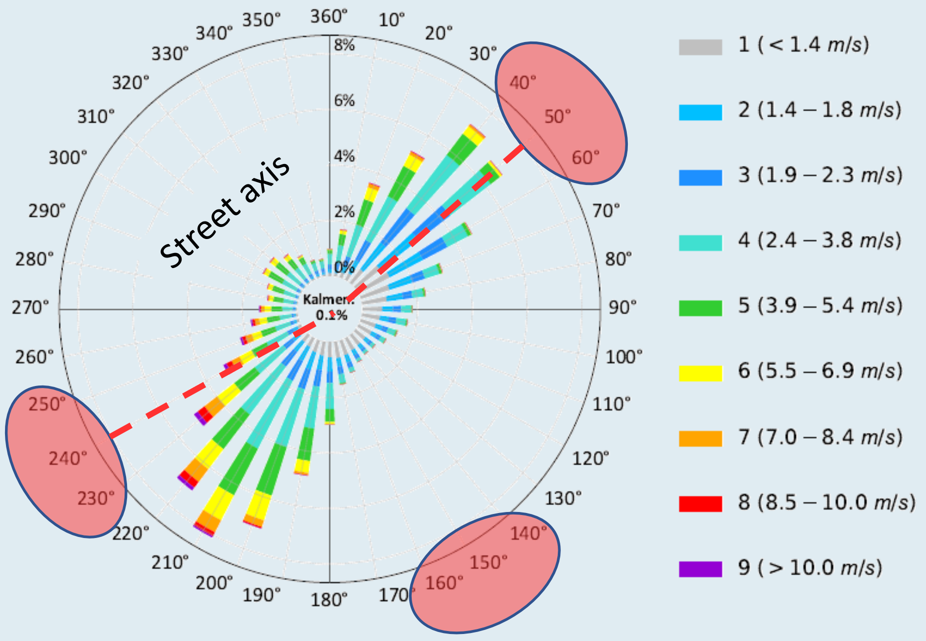
AKTerm from measurement data:

DWD_Frankfurt_2009-2018.akt

AKTerm based on DWD-CDC data - period 2009-2018

Distribution of wind direction and wind speed

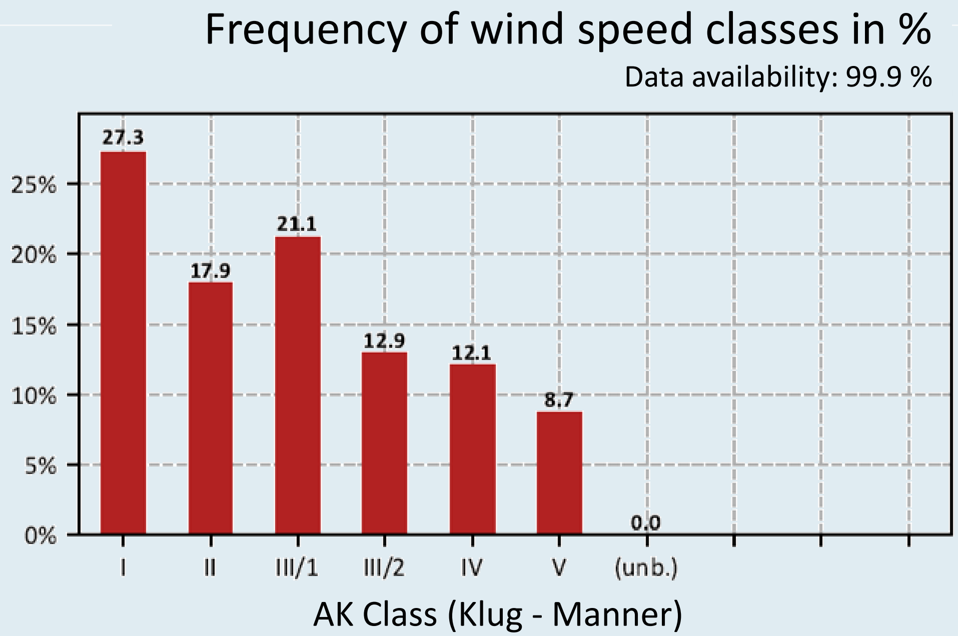
Data availability 99.9%



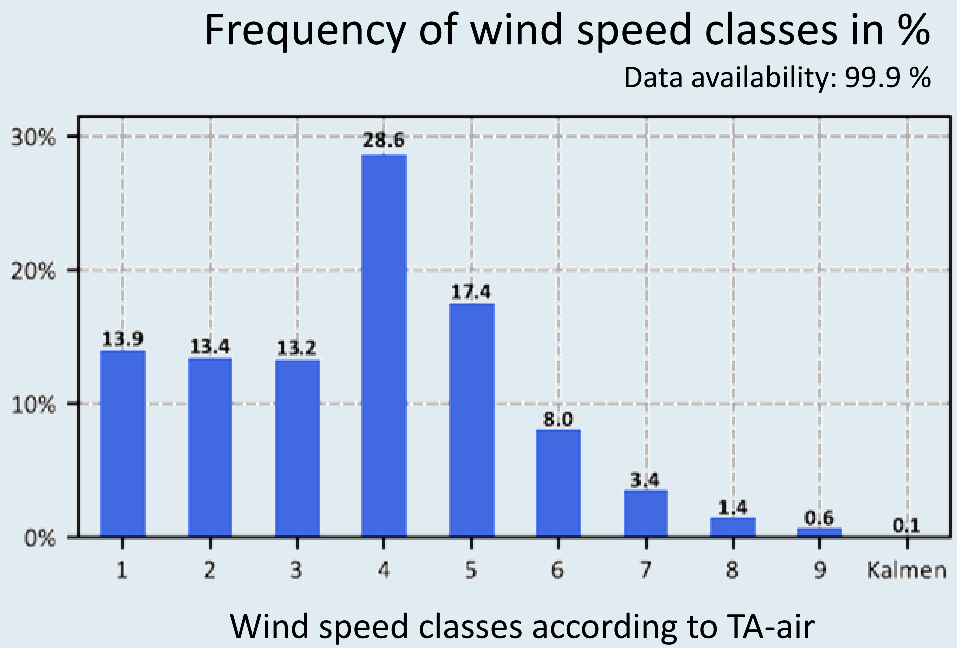
For the simulation of the effects that the Frankfurt bridges exert on the flow dynamics, atmospheric boundary conditions were chosen that correspond to those of a normal cloud-covered day with stronger overhead winds, since possible influences of the bridge structure on the ventilation only become apparent under such weather conditions.

In order to cover the wide range of theoretically occurring flow effects, three different inflow directions were selected, two of which are oriented approximately parallel and one transverse to the axis of Mainzer Landstraße. Thus, the particularly frequent NE and SW winds are also represented (see wind rose). The inflow velocity is based on the long-term average for the respective compass direction.

Wind speed and dispersion categories of the district section in which the study area is located



Mean wind speed (with actual values): 3.2 m/s
Mean wind speed (with TA air calculation speed): 3.2 m/s
Weak wind (< 1 m/s): 5.9 %



The flow dynamic effects of the Frankfurt bridges vary depending on the wind direction

The flow-dynamic influences of the Frankfurt bridges can best be highlighted by setting the simulated wind speeds of the plan case in relation to those of the zero case. A value of 1.5 thus implies an increase in velocity of 50 %, whereas a value of 0.75 implies a decrease of 25 %, with very low changes in wind velocity of less than 0.2 m/s being excluded from the outset.

The presented ratio values are - under the given premise of dynamic wind conditions - not bound to certain wind speeds, but are subject - like the corresponding processes in nature - to the so-called Reynolds independence: If one forms the ratio between two states, then this is dependent on the most different wind speeds.
speed levels can be applied. Only when the overriding wind field is so weak that it can hardly be detected in the road space, the thermal effects gain the upper hand over the flow pattern.

In addition, the simulated flow patterns of the actual and planned case can also be compared in the cross-sectional view. This shows whether and to what extent the occurring turbulences are modified by the Frankfurt bridges. The Mainzer Landstraße southwest of Francois-Mitterand-Platz and the Platz der Republik were selected as cross-sections for this purpose, as these are particularly representative bridge sections.

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Modification of the flow dynamics for actual and planned case
(I) With northeasterly inflow

Mainzer Landstraße
Illustration of the ventilation

at 1.5m above ground

Incoming flow with:
Sector wind 2.3 m/s
from 50° at 36 m a.s.l.

Extent_900x300m
Ratio of WG [planned to actual] (change >0.2 m/s)

0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 0.90
0.90 - 1.10
1.10 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00
> 2.00

direction of inflow

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Matthias Rau
Heilbronn
Created on 30.05.2022

Mainzer Landstraße
representation of the ventilation

at 9.5m above ground
(1.5 m above bridge)
inflow with: Sector wind 2.3 m/s
from 50° at 36 m a.s.l.

Extent_900x300m
Ratio of WG [planned to actual] (change >0.2 m/s)

0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 0.90
0.90 - 1.10
1.10 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00
> 2.00

direction of inflow

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With a northeasterly inflow (50°), the wind blows longitudinally through the Mainzer Landstraße. In this case, the Frankfurt bridges channel the air and in places cause an acceleration of the flow in the lower level. This is also known as the Venturi effect. The street space is thus better ventilated. On the bridges, on the other hand, the flow remains largely unchanged; only at the Platz der Republik do the buildings slow down the wind locally.

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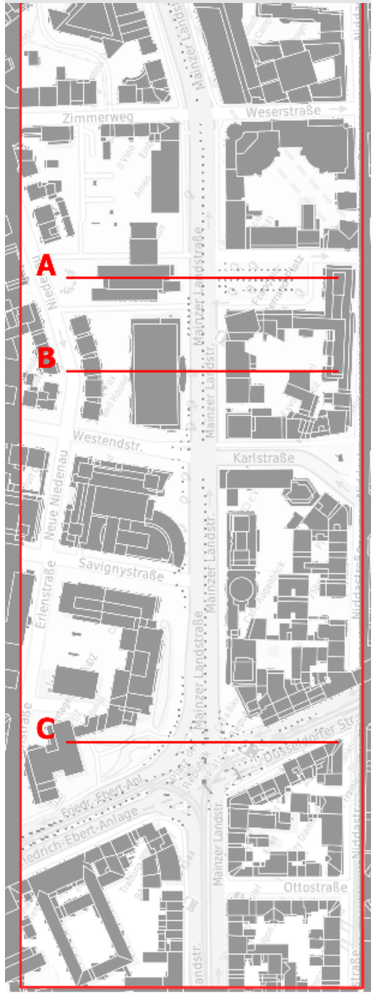
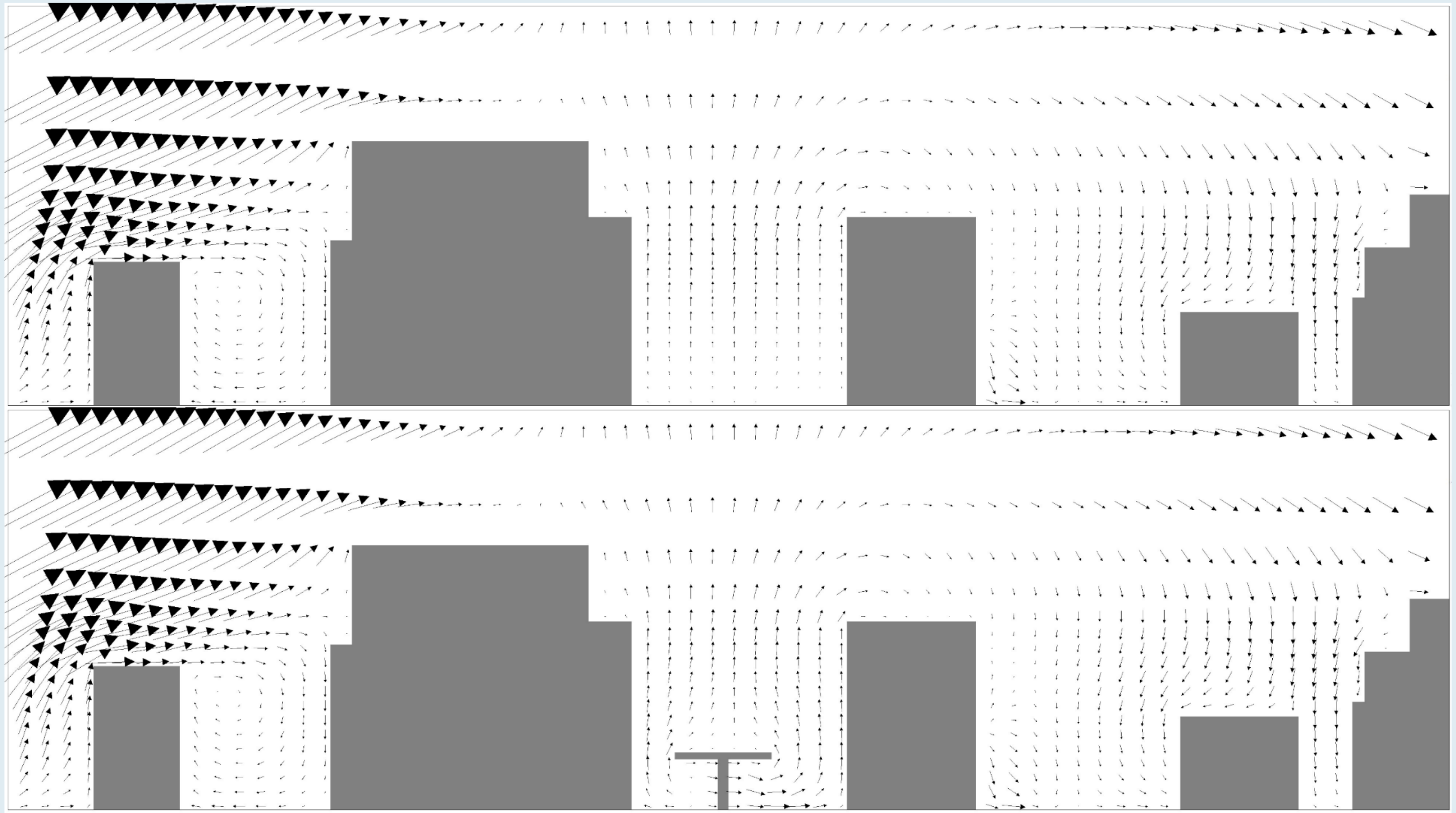
In the vertical cross-sectional view, it becomes clear that the influence on the flow dynamics remains limited to the area of Mainzer Landstraße: In the street northwest of Mainzer Landstraße as well as in the adjacent block development to the southeast, vortex systems are formed in the actual condition, which generate an upward vertical movement in the street canyon of Mainzer Landstraße. This flow pattern is also largely preserved in the plan case with the bridge structure, since the lateral deflection of the wind below the bridge is not propagated into the airspace above.

Position of the cuts



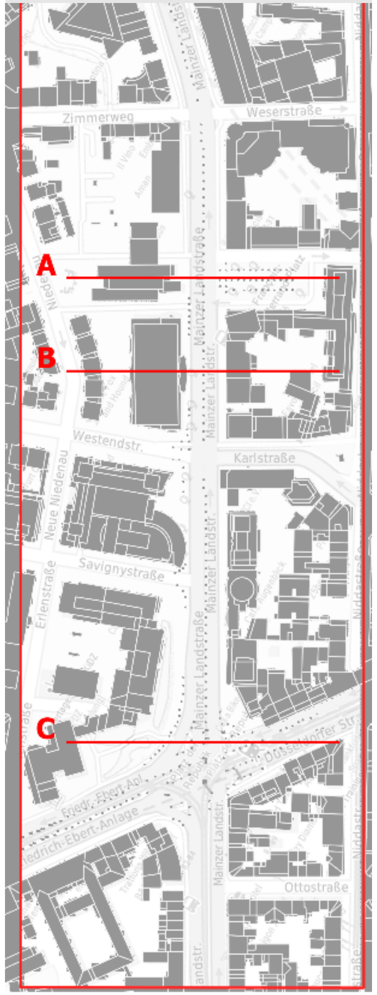
Mainzer Landstraße - Sectional view of the wind vectors - Here section B: Incoming flow from 50

Top: Zero case without bridge structure - Bottom: Plan case with bridge structure

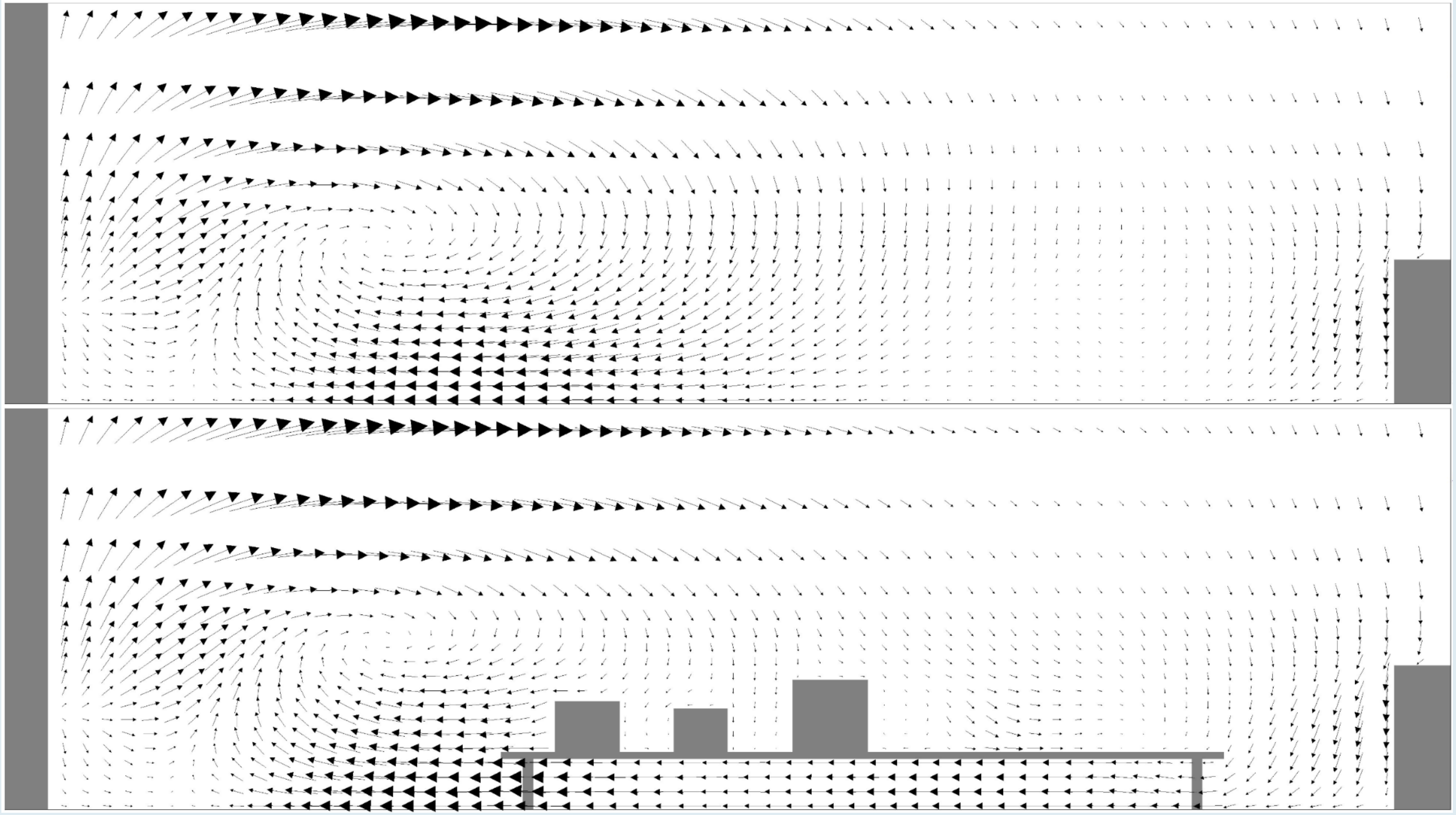


The cross-sections also reveal that the effects of the bridge construction on the local surroundings are limited: Thus, the flow pattern in the actual state is characterized by a clearly pronounced spiral vortex in the northwestern area of the intersection, which also arises almost unchanged in the plan case. The flow pattern is only modified in the vicinity of the bridge structure with the buildings standing on it, where a rotating vortex is formed due to displacement effects southeast of the building ensemble.

Position of the cuts



Mainzer Landstraße – Schnittdarstellung der Windvektoren – Hier Schnitt C: Anströmung aus 50°
Oben: Nullfall ohne Brückenbauwerk – Unten: Planfall mit Brückenbauwerk



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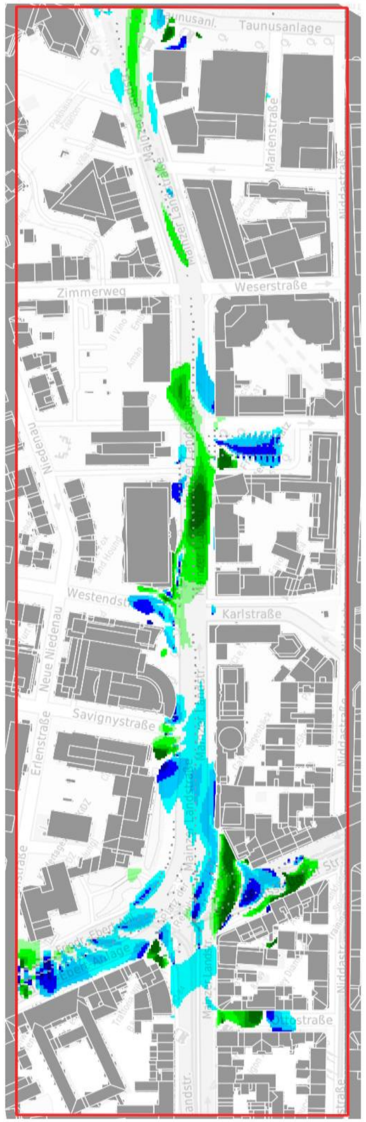
Modification of the flow dynamics for actual and planned case
(II) With inflow from the southwest



Mainzer Landstrasse
Presentation
of the aeration

at 1.5m above ground

Anstrémung with:
Sector wind 4.7 m/s
from 240° in 36 m U.G.

Extent_900x300m
Ratio of WG [planned to actual] (change >0.2 m/s)

0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 0.90
0.90 - 1.10
1.10 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00
> 2.00

direction of inflow

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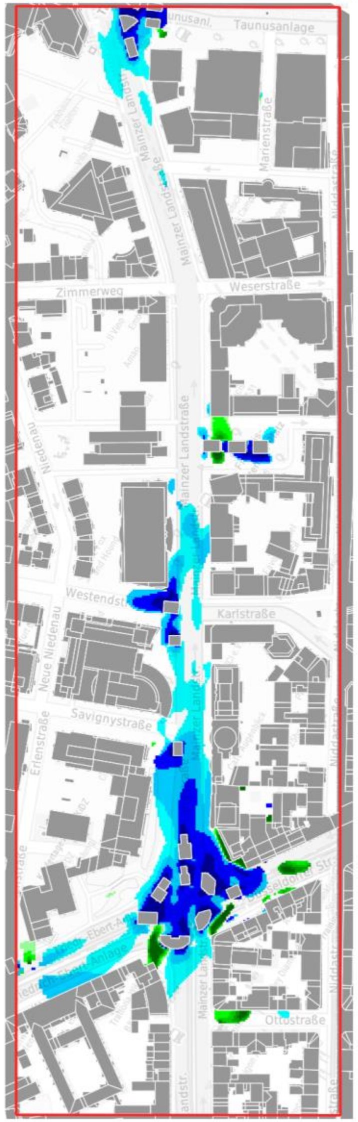

Mainzer Landstraße
Illustration
of the ventilation
at 9.5m above ground
(1.5 m above bridge)
Incoming flow with:
Sector wind 4.7 m/s
from 240° at 36 m a.s.l.

Extent_900x300m
Ratio of WG [planned to actual] (change >0.2 m/s)

0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 0.90
0.90 - 1.10
1.10 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00
> 2.00

direction of inflow

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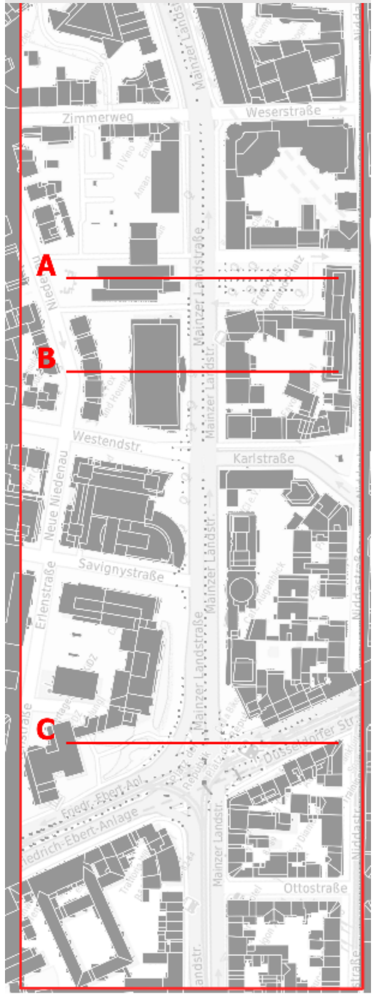
In the case of an inflow from the southwest (240°), a complex juxtaposition of areas of increased and reduced wind speed occurs, which ultimately cancel each other out. Analogous to the flow from the northeast, acceleration effects can also occur under the bridge structure, whereas the wind speed on the Frankfurt bridges decreases.

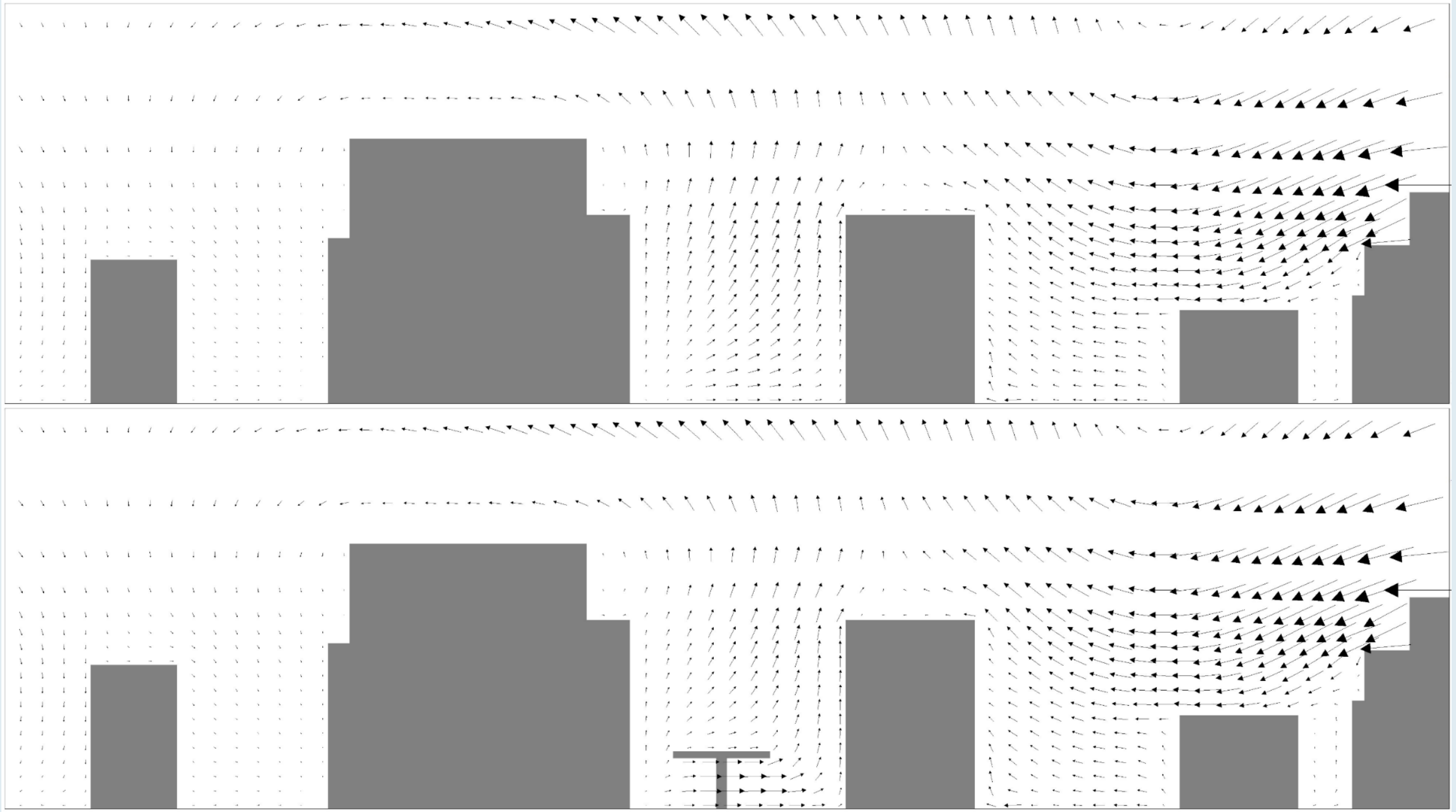
As in the other two cases, however, the effects are concentrated exclusively in the immediate area of Mainzer Landstraße, so that there are no long-distance effects on the neighbouring buildings.

If one compares the vertical sections of the actual state and the planned state with an inflow from the southwest parallel to the road, then differences in the flow pattern are only recognizable for the area of Mainzer Landstraße: Due to the obstacle effect emanating from the bridge structure, lower velocities occur above the bridge in the planned case and higher velocities in the lower area. Below the bridge level, a reduced aeration effect is therefore not to be assumed.

Position of the cuts



Mainzer Landstraße - Sectional view of the wind vectors - Here section B: Incoming flow from 150°.
Top: Zero case without bridge structure - Bottom: Plan case with bridge structure



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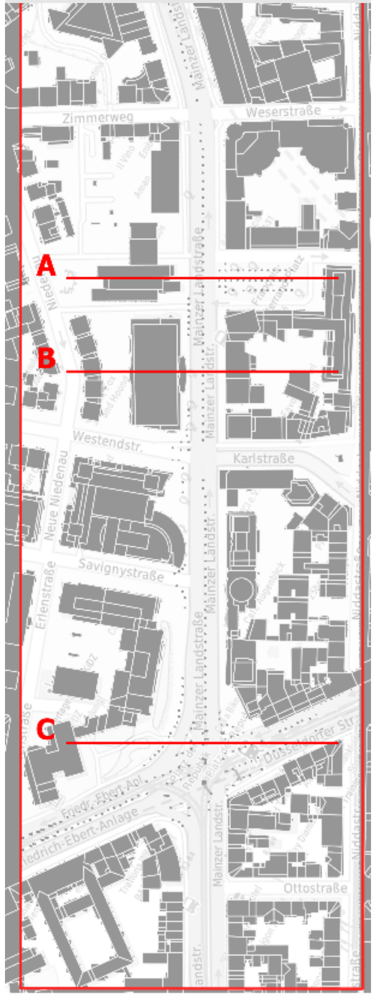
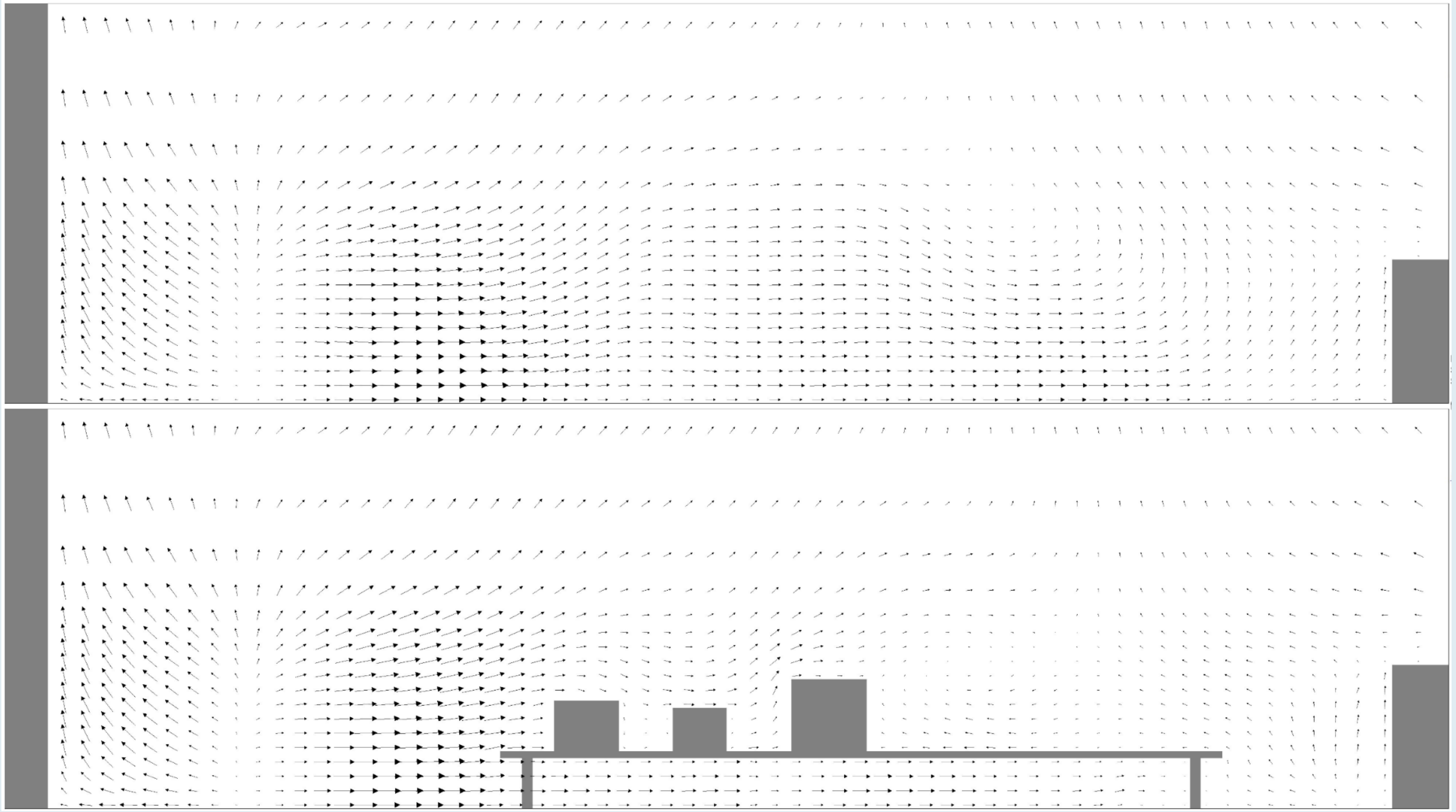
The situation at the Platz der Republik is more complicated: There, the upwind building complex in the northwest leads to the formation of a complex vortex system, which, however, is almost unchanged in the actual and planned state. In both cases, a crossflow is induced towards the southeast, which is in turn locally modified by the bridge structure. It follows that the velocity level below and above the bridge level is locally reduced to a small extent.

Position of the cuts



Mainzer Landstraße - Sectional view of the wind vectors - Here section B: Incoming flow from 150°.
Top: Zero case without bridge structure - Bottom: Plan case with bridge structure



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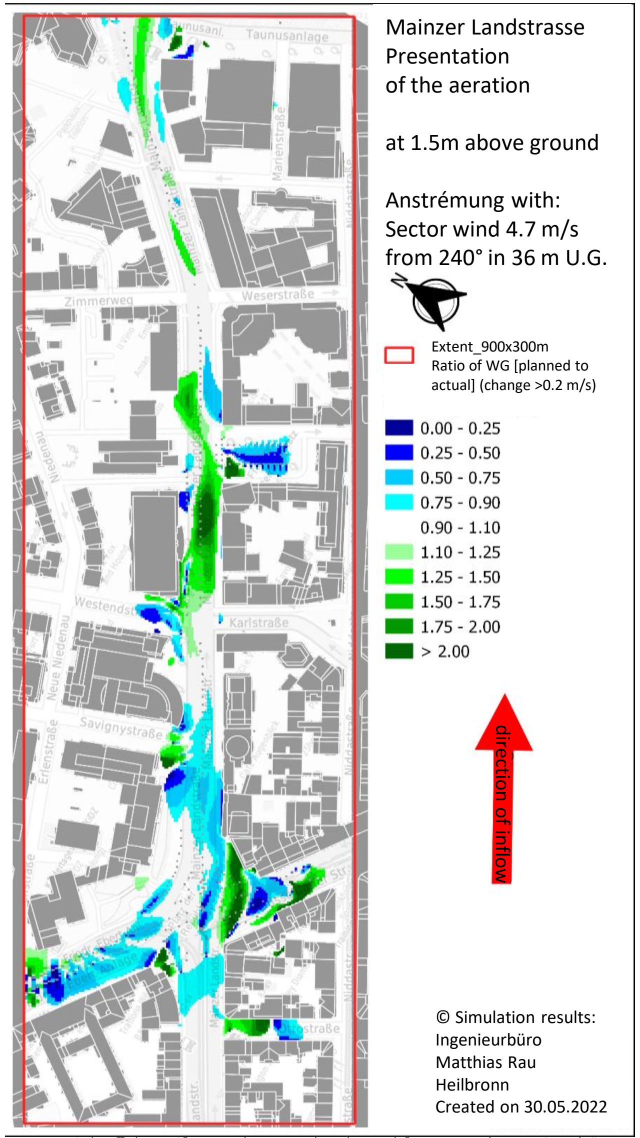
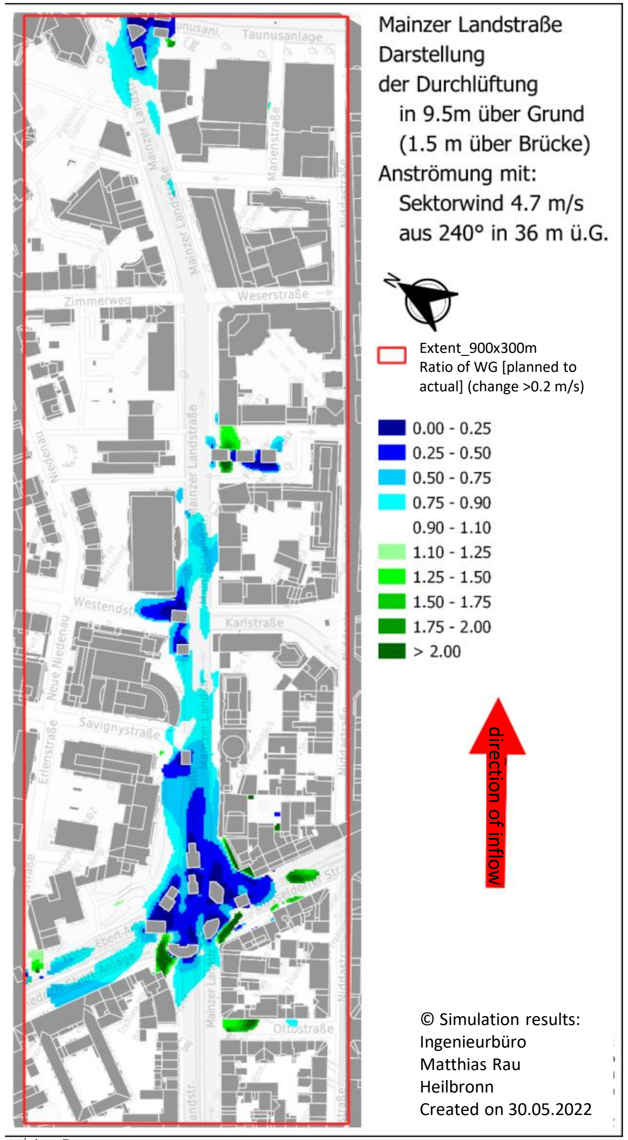
Modification of the flow dynamics for actual and planned case
(III) With inflow from the southwest





In the case of an inflow from the southwest (240°), a complex juxtaposition of areas of increased and reduced wind speed occurs, which ultimately cancel each other out. Analogous to the inflow from the northeast, acceleration effects can also occur under the bridge structure, whereas the wind speed on the Frankfurt bridges decreases.

As in the other two cases, however, the effects are concentrated exclusively in the immediate area of Mainzer Landstraße, so that there are no long-distance effects on the adjacent buildings.

Interim conclusion: The Frankfurt bridges can be considered unproblematic for ventilation and the air-hygienic situation

In accordance with expectations, the Frankfurt bridges as flow obstacles lead to local modifications of the wind field, which is pre-dominated by the high buildings on Mainzer Landstraße. Small-scale, highly complex effects occur in the dynamic flow pattern, with zones of reduced and zones of increased wind speed balancing each other out.

Under the Frankfurt bridges, wind acceleration may occur in some places, resulting in better ventilation of the street space. However, there is a tendency for many flow patterns that already occur in the current state of Mainzer Landstraße not to be significantly affected, which is due to the columnar character and associated wind permeability of the Frankfurt bridges.

In any case, the dynamic effects of the bridges are always limited to the immediate vicinity, which is why no far-reaching effects can be assumed.

Since Mainzer Landstrasse is considered a "worst-case" example of the Frankfurt bridges' route due to its exceptionally high and dense perimeter development, all other - less critical - route sections should at best exhibit similar flow patterns and not cause any deterioration in the dynamic effects.

If, contrary to expectations, the urban climatic investigation of other critical points in the bridge route should reveal negative effects in advance, there is also the possibility of providing the bridge corpus with air holes protected by railings in order to improve ventilation.

In addition to the thermal and dynamic analyses under consideration, investigations of the immission load are also common urban climatic pre-planning analyses - which could be omitted here due to the long planning horizon.

The "Frankfurt Bridges" construction project is expected to require a planning phase of 5 years and a construction period of 10 years. In this time horizon, a drastic change in the immission landscape can be expected due to the change in vehicle engines in Germany. Since vehicle emissions, while not 100%, account for a significant portion of the pollutant load on the roads, it is not possible at this point in time to make valid planning analyses for the effects of the Frankfurt bridges in the future on the current data basis.

However, should the introduction of e-cars and hydrogen vehicles proceed at the planned rate, such a significant improvement in the air in our cities can be expected that the bridge structure should have extremely little impact by today's standards in such a "clean" environment.

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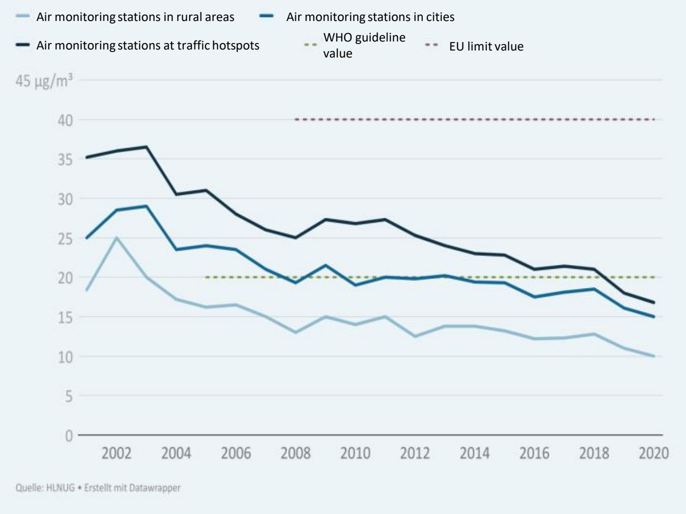
Immission levels in Hesse have been falling for years - By the time the Frankfurt bridges are completed - in 2037 at the earliest - the situation is likely to ease further

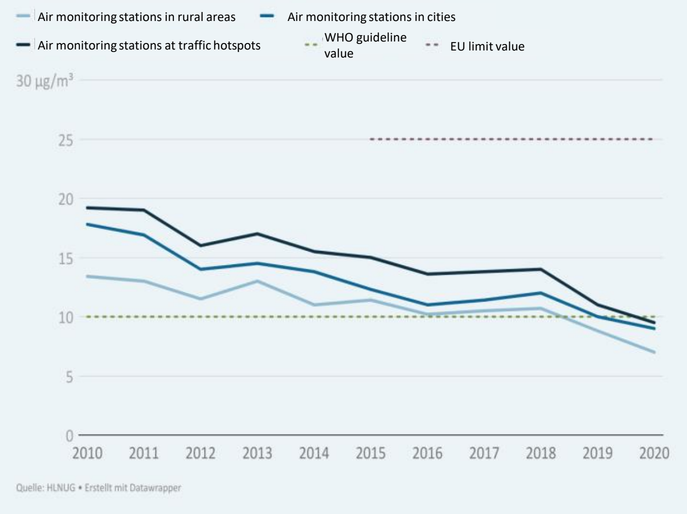
Immission levels from inner-city traffic have fallen continuously in recent decades. In Hesse, for example, as in the rest of Germany, emissions are already below the EU limits. This is due, among other things, to improvements in the emission values of internal combustion engines, which have to meet increasingly stringent requirements. However, a greater reduction can only be expected when internal combustion engines disappear from cities altogether.

Electric cars are being touted as the emission-free alternative of the future, but even they cannot completely escape responsibility for particulate pollution: The reason for this is the general brake abrasion of vehicles - and e-cars are about 300 kg heavier than conventional gasoline engines due to their large batteries, according to studies, so more abrasion is generated by tire rubber and brake pads when braking. However, this problem is being counteracted by increased lightweight construction, recuperation technology and also research into multi-disc brakes, so that by 2035 the trend is again expected to be offset to some extent.

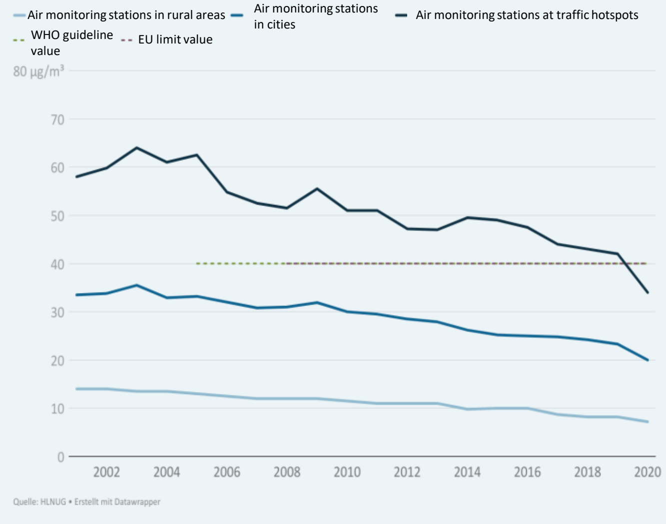
Development of annual mean PM10 values in Hesse



Development of PM2.5 annual mean values in Hesse



Development of the annual mean NO_2-values in Hesse



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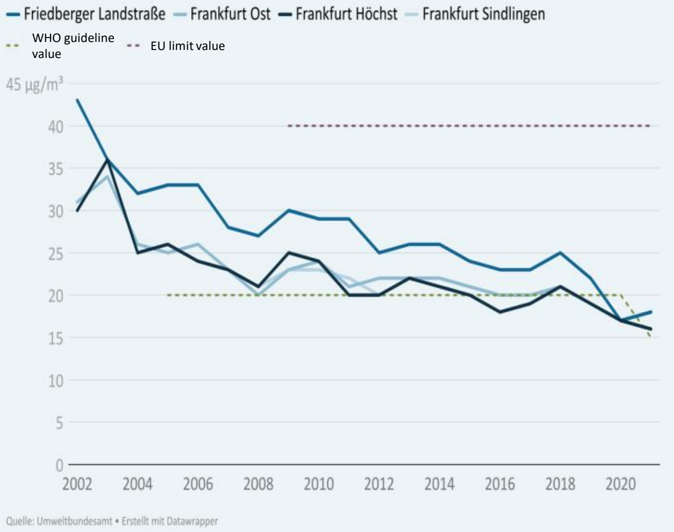
Pollution levels in Frankfurt have also shown a downward trend in recent years

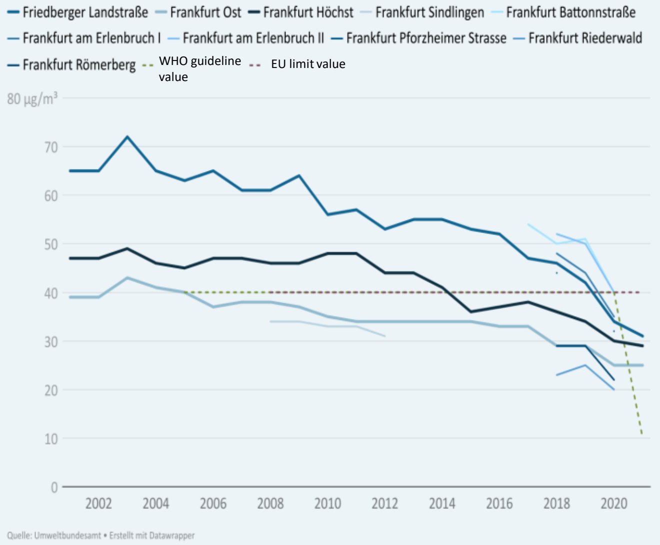
The fact that the EU limit values for the annual mean values of PM10 and PM2.5 have not been exceeded for many years is an indication that Frankfurt's city air has also become increasingly clean in recent years. At the same time, however, the WHO guideline values, which have only been met in isolated cases and will be tightened again in 2020, make it clear that there is still a great need for action to ensure healthy air quality in Frankfurt.

Development of PM10 annual mean values in Frankfurt am Main

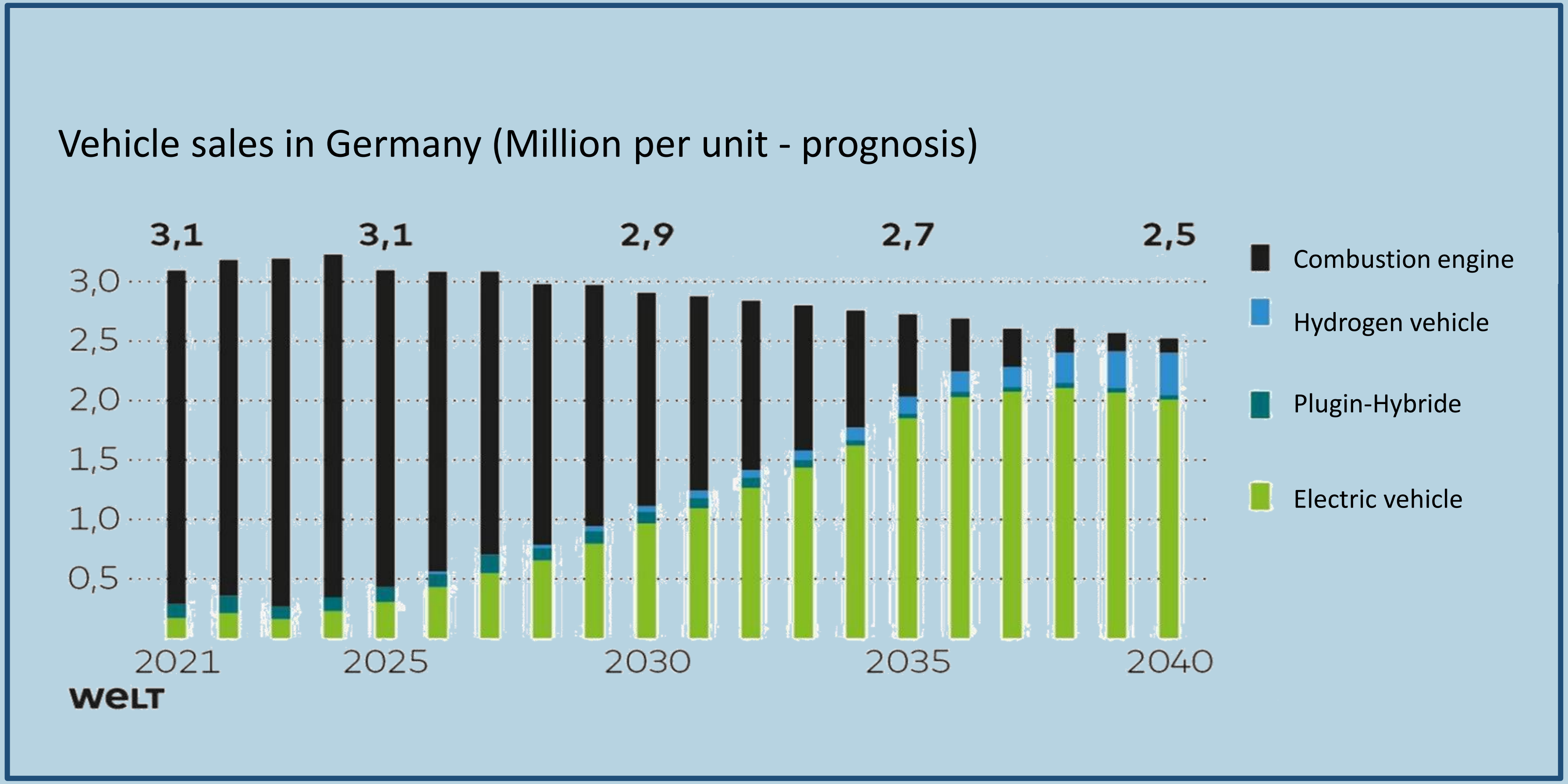


Development of PM2.5 annual mean values in Frankfurt am Main

Development of NO_2 annual mean values in Frankfurt am Main



By the time the Frankfurt bridges are completed in 2035 - 2040, the proportion of internal combustion engines will have fallen dramatically as a result of the steady modernization of transport fleets - and with it the pollution levels on the city's roads



For each city, however, it must be examined separately whether the concept of the Frankfurt bridges also produces a positive - or at least neutral - effect on the urban climate there

Many cities suffer from housing shortages, water shortages for their green spaces, and space shortages for their very ambitious renewable energy expansion goals.

The concept of the Frankfurt bridges could help here - but in order to be able to make definitive statements about its urban climatic compatibility, a separate microclimatic simulation of the potential effects caused by the bridge structures is indispensable for every other city.

This is because not only the building structure of a city, but also many other factors such as the regional climate, the location of the city in the relief, etc. are of central importance for the assessment of such an infrastructural construction project.

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Conclusion: Thermally, the Frankfurt bridges are likely to be an enrichment for the city climate; in terms of ventilation and air hygiene, they are unproblematic

From a thermal point of view, the shadows cast by the Frankfurt bridges, their discreet structure and their intesive greenery provide a climatic enhancement of the Mainzer Landstrasse study area.

Under the Frankfurt bridges, wind acceleration can occur in some places, which improves the ventilation of the road space - only in a few places the wind speed is affected to a comparatively small extent. Overall, however, the existing flow patterns in the study area are only slightly modified, as the column structure of the bridges ensures a high wind permeability.

In both cases, the thermal and dynamic effects are always limited to the vicinity of the bridge structure. Since the study area is one of the most critical points in the course of the bridges in terms of urban climate, the analysis and simulation results can be transferred to all other bridge sections.

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Frankfurt


Frankfurt: Current urban climate


Effects of the bridges


Measures next to the bridges


The CO_2 balance sheet of the bridges


Urban Climate - Global Climate: Old Uncharted Territory Worldwide


The goal: to arm the city against drought and floods


The green metropolis of the future


Vitalization of the urban green

EMPLOYEES

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Bridges
Energy
Geoinformation

Communication
Art & Culture
Urban Green & Nature
Urban climate - world climate

Statics
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Technology & IT
Packing

Visualization & Images
Water
Webpage & Design

Law
Finance
Implementation

Critical sparring partners:
Professors
Professionals
Inspirers & Supporters

Measures next to the bridges

The bridges enable measures to improve the urban climate in their extended surroundings

Measures are also being implemented in the vicinity of Frankfurt's bridges to positively influence the city climate: The evaporative coolness in the city centre is promoted by using the bridge ring line to unseal, plant and irrigate 40,000 m^2 area in Frankfurt and to supply a further 200,000 m^2 of green space next to and near the bridge with water. The bridges' water system will also enable the planting and supply of around 1,000 more trees in the city centre, which will also improve their microclimatic environment by casting shade, binding pollutants and producing fresh air. In addition, road surfaces will be renewed in the course of the bridge construction. Instead of the traditional dark grey, they will now be finished in a lighter colour with regard to summer heat, which will allow the albedo effect to take effect there.

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Chapter content: The chapter describes the package of measures that will be implemented in the bridge context to improve the urban climate

The most important bundle of measures deals with the unsealing and planting of areas in the city, as well as the irrigation of already existing, undersupplied green areas.

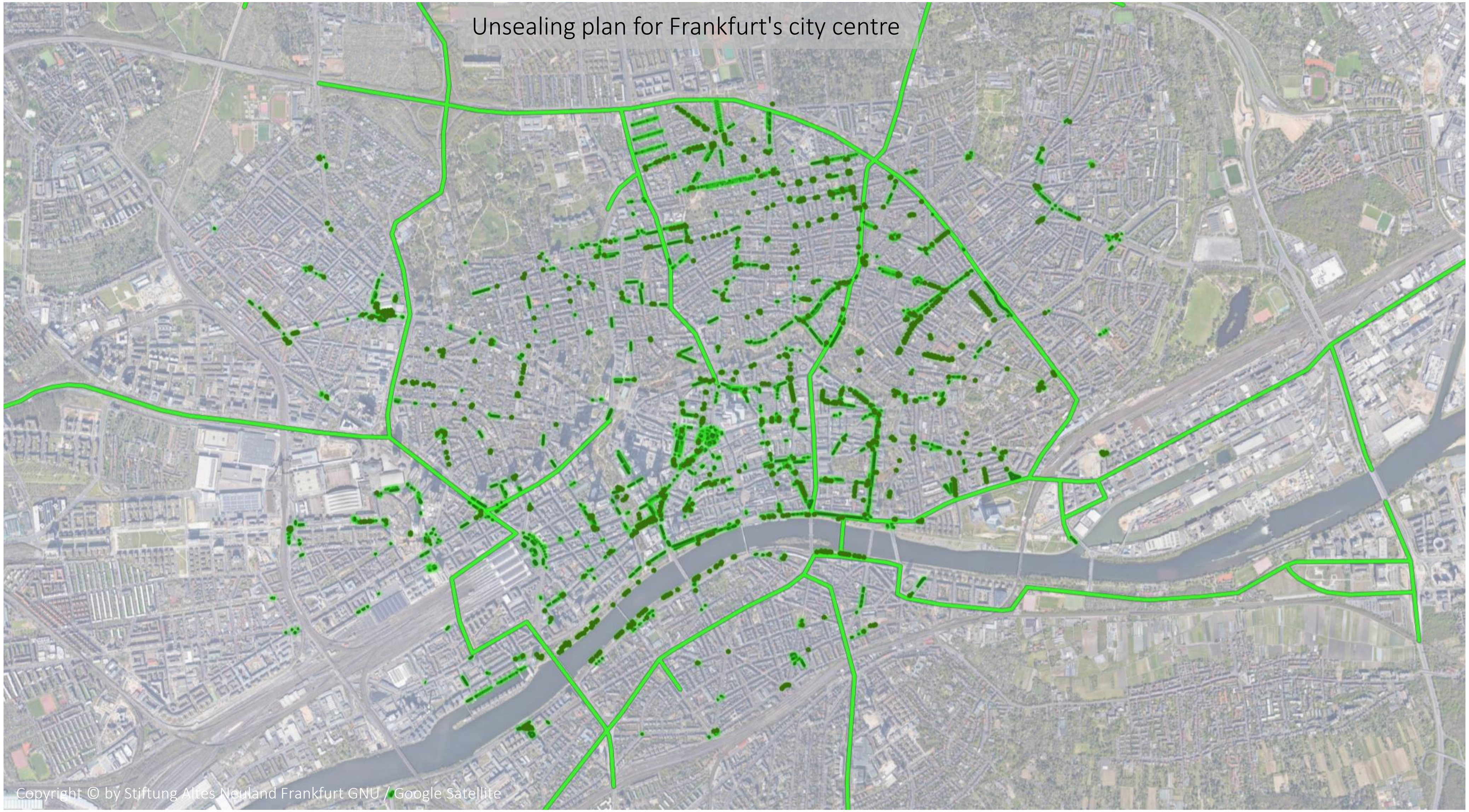
By pushing autonomous traffic concepts, a large part of the parking spaces in Frankfurt will no longer be needed in the future - and will thus be available for further unsealing and greening measures as well as tree planting.

Many areas next to the Frankfurt bridges are also designed to be as brightly coloured as possible, so that they heat up less in the summer.

In the course of the construction of the Frankfurt bridges, numerous other positive measures for the urban climate can be implemented

Make the roadsides to the right and left of bridges capable of infiltration: If, during heavy rainfall in summer, the precipitation infiltrates instead of being "disposed of" in the sewage system, then not only is the infiltration area itself cooled, but even long after the rain has stopped, the ambient temperature is lowered by extracting heat from the air for the evaporation of the water. In climatology, we therefore also speak of "evaporative cooling" and the "oasis effect" of green spaces. However, in order to make them capable of infiltration, areas must also be changed in the subsoil.

In total, more than 40,000 square metres of new unsealed and planted areas can be created in Frankfurt's city centre - thanks to the bridges' water system



Evaporative cooling through infiltrative surfaces - a drop in the ocean?

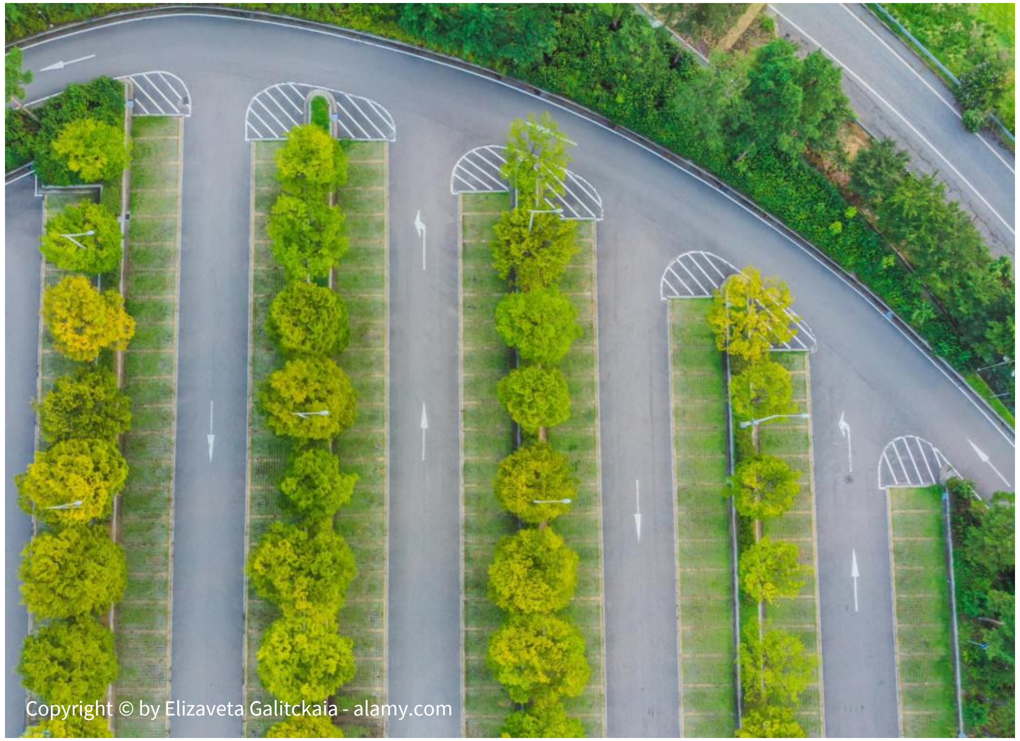
In the case of land unsealing and its impact on the local urban climate, three types of unsealing must be distinguished:

1. simply unsealed area covering the water-absorbing space with soil, gravel or grating
2. unsealed area covered exclusively with grass
3. unsealed area with denser and higher plant cover

Compared to darkly asphalted surfaces, both simply unsealed surfaces and lawns are a thermal enrichment:

A grassy parking lot surface, for example, has surface temperature differences of up to 8 °C on hot summer days compared to an asphalt surface (if it is not dried out, of course).

However, even better than simply unsealing or providing lawns is to plant the areas with lush vegetation such as shrubs or perennials.



However, large-crowned trees are the most suitable: as large shade trees, they have the highest cooling effect among urban vegetation, because shade causes more significant cooling in the area close to the ground than evaporation in the canopy further away from the ground. However, since it is often possible to unseal but not always to plant a tree, unsealing is another important urban planning measure alongside facade and roof greening to increase evaporative cooling.

Good urban planning ensures unsealing and infiltration - even where nothing can be planted

In order to allow stormwater to infiltrate in a city during heavy rain events, not only must surfaces be made permeable, but spaces must be created in the subsoil where water can collect.

These spaces can either be actual voids with a grate-like cover over them; or they can be filled with coarser gravel to finish on top with a denser, firmer, but water-permeable layer.

In this way, formerly sealed parking lots or street medians can be unsealed and contribute to the creation of the "water-sensitive" city of the future.

In the course of the construction of the Frankfurt bridges, road surfaces will be renewed after completion of construction anyway, so that for the areas to the right and left of the bridges with a certain gradient, drainage or infiltration can also be achieved under the asphalted road space. Frankfurt can thus take another step towards becoming a "sponge city".


Tree center strip


Roadside bed

Roadside parking

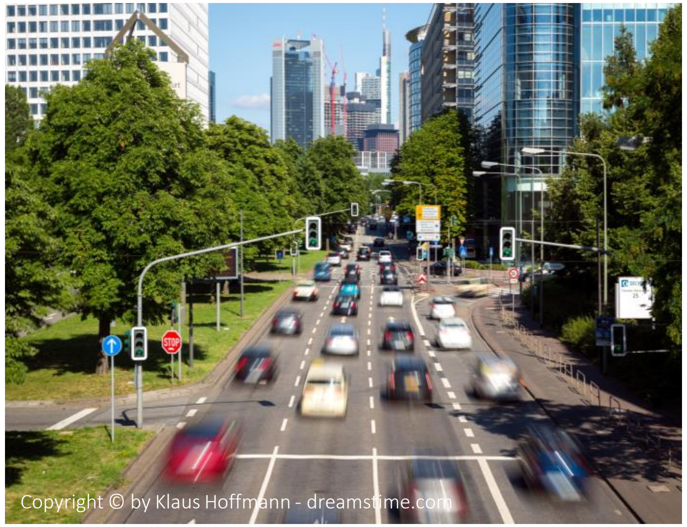
Old New Territory
Frankfurt

The most important contribution of the Frankfurt bridges to the unsealing of the city: Reduction of the number of vehicles and thus of the required parking spaces - through autonomous, centrally controlled urban traffic

With the autonomous traffic on the Frankfurt bridges, the world's largest inner-city quarter is being created in which a complete world of demand is actually covered by self-driving vehicles. This unique and state-of-the-art test area is the starting point for successively implementing autonomous traffic under the bridges in certain parts of the city or zones - as soon as the systems are sophisticated and the learning curves have been run through.

A transfer to city districts or zones under the bridges can only be expected in a few decades and will also have to work with a transition period: During this time, vehicles will still be individually steered and will only become autonomously driven or controlled by a control center as soon as they enter such a district zone. Up to the limits of these zones, they will have to remain individually steerable.

This means that there is still a long way to go - forecasts assume half a century or more.



Freed-up parking space can be converted into green areas or cycle paths

But when this development towards autonomous urban traffic is complete, the number of vehicles required (including "individually transporting vehicles") will be reduced by up to 90 %. Accordingly, the required parking space in Frankfurt will also decrease significantly.

If parking spaces today presumably take up around 9 km^2 of the 52 square kilometres of traffic area in Frankfurt, this will then be less than 1 km^2 . This means that 8 km^2 can be unsealed and greened or even planted with trees. Entire streets will be given a different look - and a different thermal urban climate.

Good urban planning relies on the albedo effect wherever

Create lighter surfaces to the right and left of the bridges: When the sun hits bright surfaces on hot days, they do not heat up as much as dark surfaces: This is because more of the incident solar radiation is reflected and the reflected radiation is not available to heat the human body, for example. In climatology, this effect is called the "albedo effect". It is traditionally used in hot countries, which is why you find so many lighter buildings and paving stones in southern Europe.

If the pavement is renewed in the course of bridge construction in a street, the pavements to the right and left of the construction site can also be renewed. Large city centres in particular benefit from lighter surfaces - thermally, but also visually. But beware: bright surfaces contribute to the well-being of walkers, but they must not be glaringly bright - otherwise they have the opposite effect and reduce the sense of well-being.

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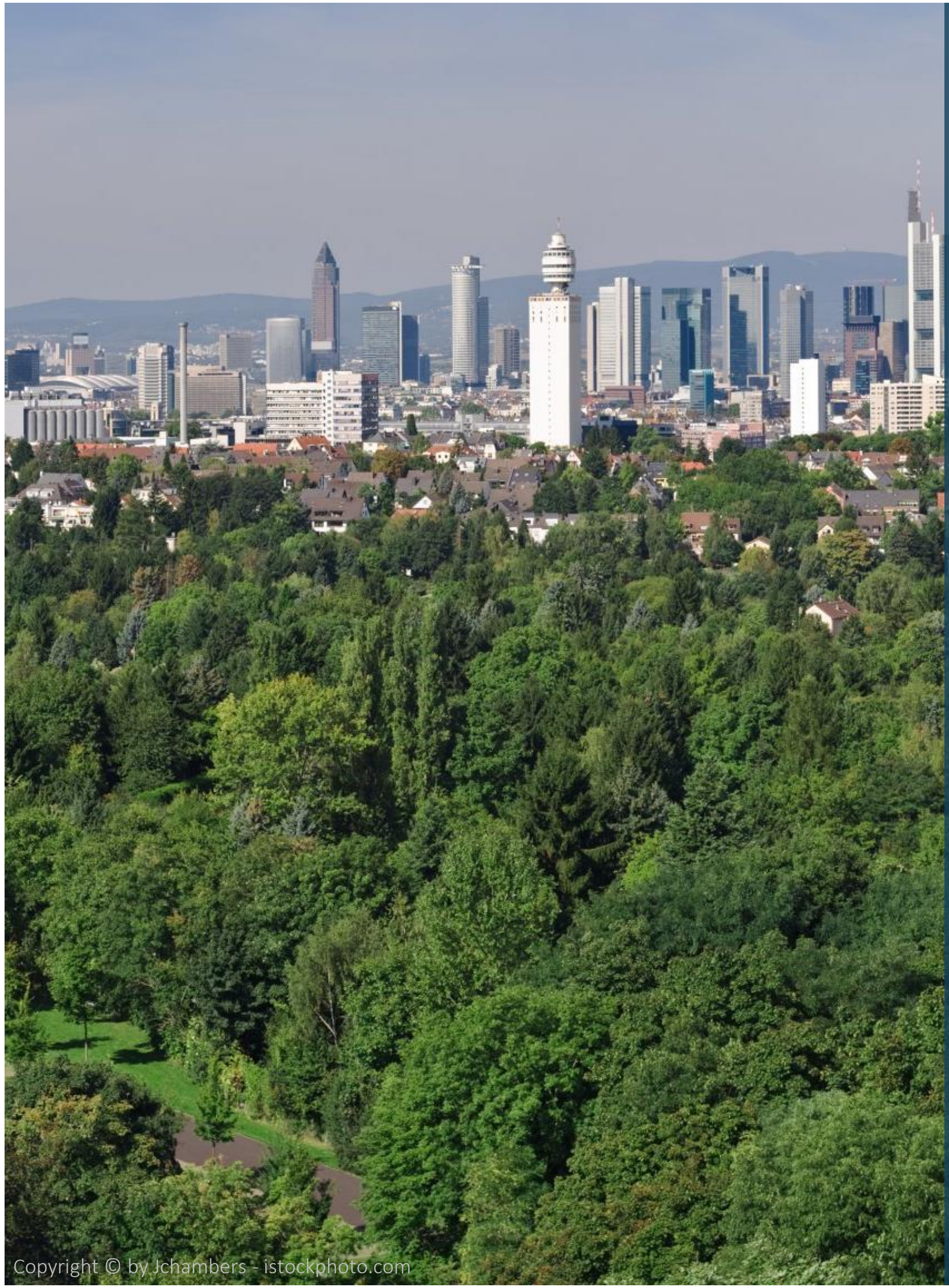
The principle of making all new surfaces in the road area light-coloured is of course also followed on the bridges themselves

Traffic and walking paths on the bridges are always brightly designed



Conclusion: The multifaceted bundle of measures away from Frankfurt's bridges gives the entire city a more pleasant climate

The Frankfurt bridges will not only change the appearance of Frankfurt along the bridge network. More distant areas of the city will also be upgraded with the help of a wide-ranging bundle of measures made possible by the bridges' water system:

Many surfaces in the vicinity of the Frankfurt bridges are being unsealed, greened and planted; this allows more water to evaporate and lower the ambient temperature. At the same time, many surfaces are being made as light as possible to counteract heating of the air on hot summer days. In addition, the numerous newly planted trees provide cooling shade.

In the long term, Frankfurt bridges will reduce the need for highly sealed traffic areas through their autonomous traffic. Parking spaces that have become superfluous can then also be landscaped or planted with trees and have a positive impact on the urban climate.

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Frankfurt: Current urban climate


Effects of the bridges


Measures next to the bridges


The CO_2 balance sheet of the bridges


Urban Climate - Global Climate: Old Uncharted Territory Worldwide


The goal: to arm the city against drought and floods


The green metropolis of the future


Vitalization of the urban green

EMPLOYEES

Architecture	Communication	Statics	Visualization & Images	Law	**Critical sparring partners:**
Bridges	Art & Culture	Transportation	Water	Finance	Professors
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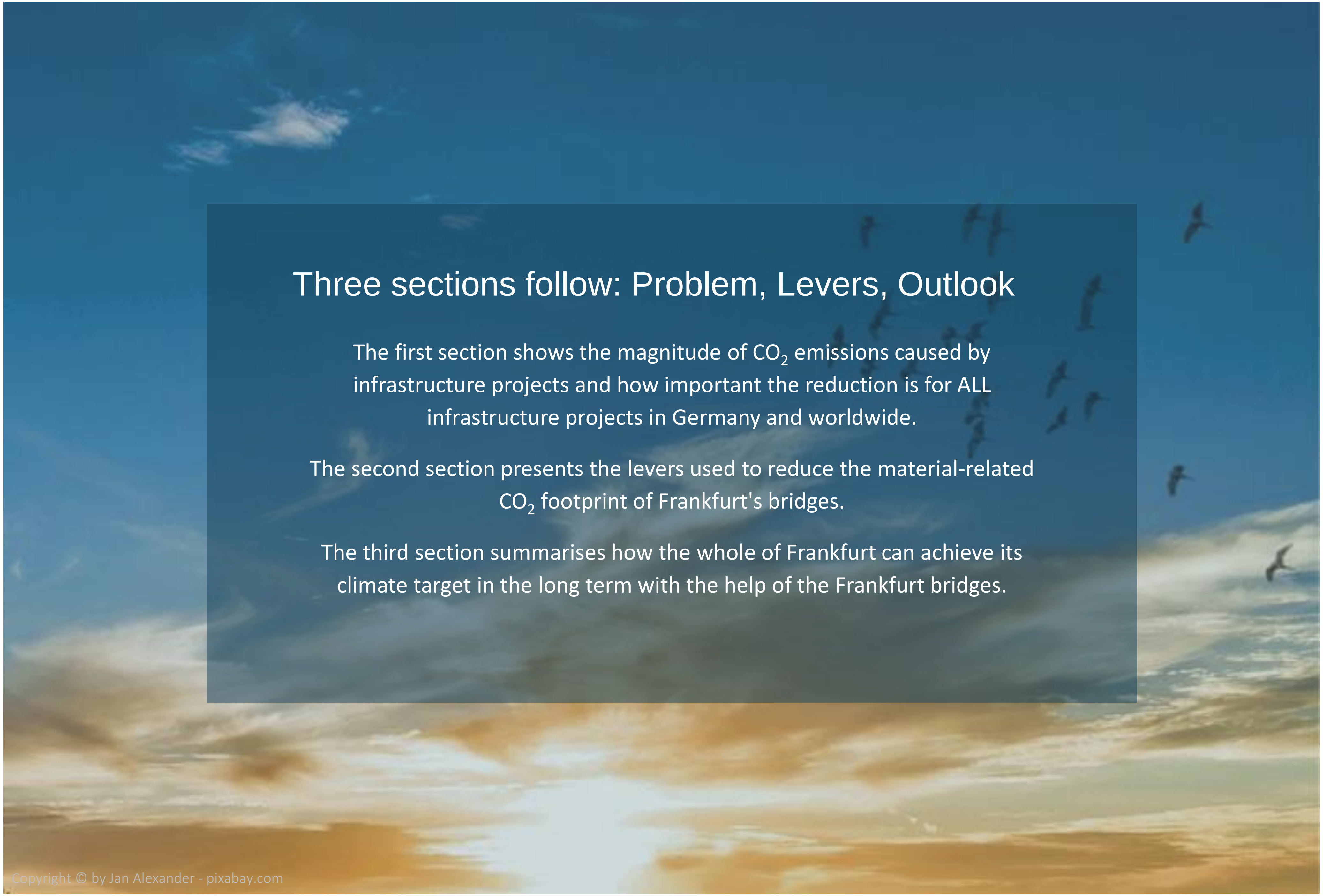
Geoinformation	Urban climate - world climates	Packing			Inspirers & Supporters

The carbon footprint of bridges

Old New Territory
Frankfurt

The CO_2 balance of the bridges can be reduced by 75%

Numerous measures can be taken to reduce the CO_2 balance of Frankfurt's bridges to a quarter: The most important levers include the use of steel produced in an almost CO_2-neutral manner, the favoring of climate-friendly vehicle propulsion energy and the generation of green electricity. Furthermore, where there are no buildings on the bridges, low-CO_2 concrete can be used - as a showcase for innovation.



Three sections follow: Problem, Levers, Outlook

The first section shows the magnitude of CO_2 emissions caused by infrastructure projects and how important the reduction is for ALL infrastructure projects in Germany and worldwide.

The second section presents the levers used to reduce the material-related CO_2 footprint of Frankfurt's bridges.

The third section summarises how the whole of Frankfurt can achieve its climate target in the long term with the help of the Frankfurt bridges.

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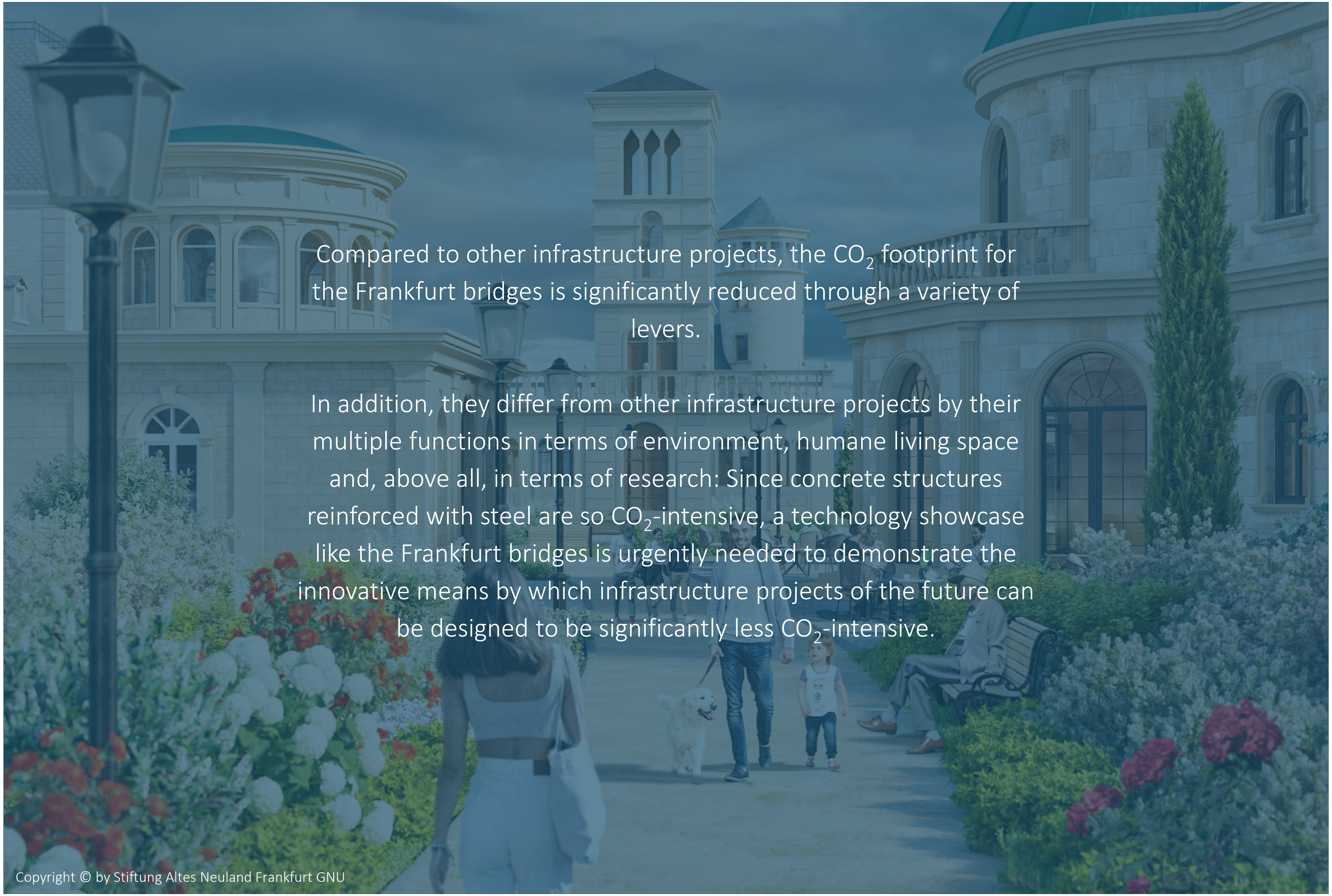
Frankfurt

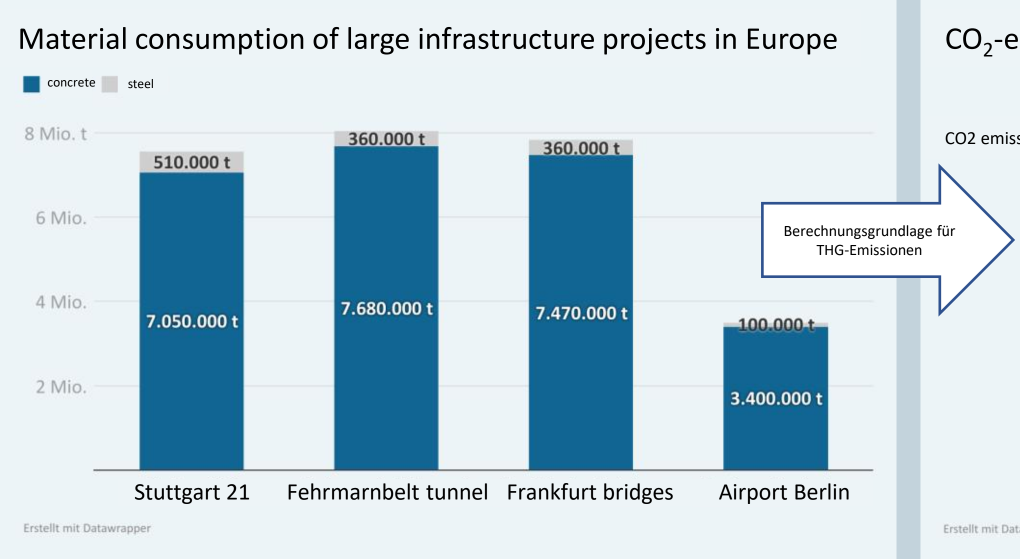


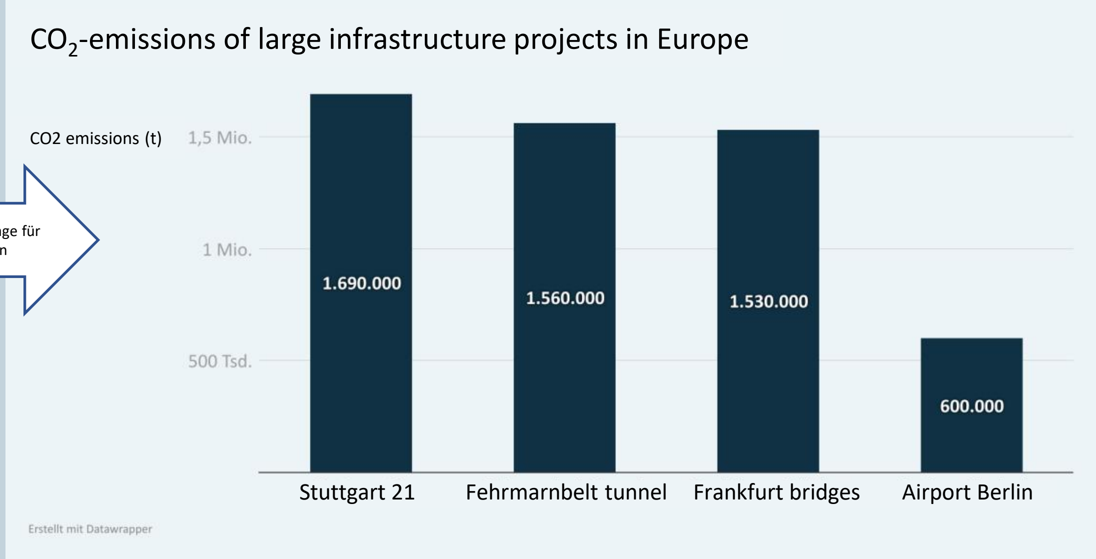
Compared to other infrastructure projects, the CO_2 footprint for the Frankfurt bridges is significantly reduced through a variety of levers.

In addition, they differ from other infrastructure projects by their multiple functions in terms of environment, humane living space and, above all, in terms of research: Since concrete structures reinforced with steel are so CO_2-intensive, a technology showcase like the Frankfurt bridges is urgently needed to demonstrate the innovative means by which infrastructure projects of the future can be designed to be significantly less CO_2-intensive.

Based on conventional methods, the Frankfurt bridges are comparable to other infrastructure projects of this size in terms of GHG emissions

Although the Frankfurt bridges serve many positive purposes and are not expected to produce as many GHG emissions as tunnelling and deep laying, the emission value of around 1.5 million tons of GHG (CO_2-equivalent GHG emissions*) from construction materials is still too high. All reduction options must therefore be explored and implemented.





CO_2, CO_2e und THG explained

CO_2-equivalent Greenhouse Gas emissions

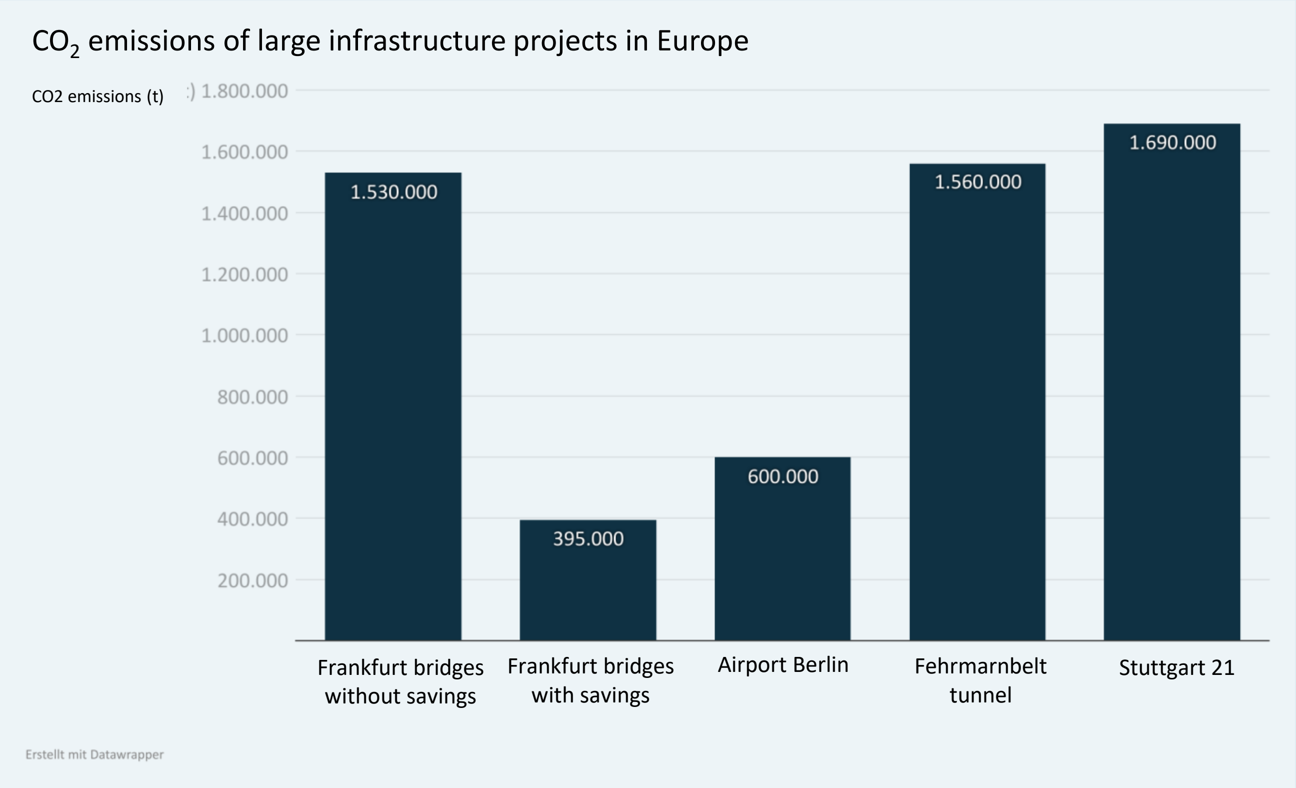
In addition to carbon dioxide (CO_2), probably the best-known greenhouse gas, there are also other greenhouse gases that have an impact on the climate, e.g. methane (CH_4) or nitrous oxide (N_2O).

Since their global warming potential differs from that of CO_2 , they are usually converted into CO_2 equivalents (CO_2 e). For example, one tonne of methane contributes 28 times as much to the greenhouse effect over 100 years as one tonne of CO_2 , i.e. 28 tons of CO_2 equivalents.

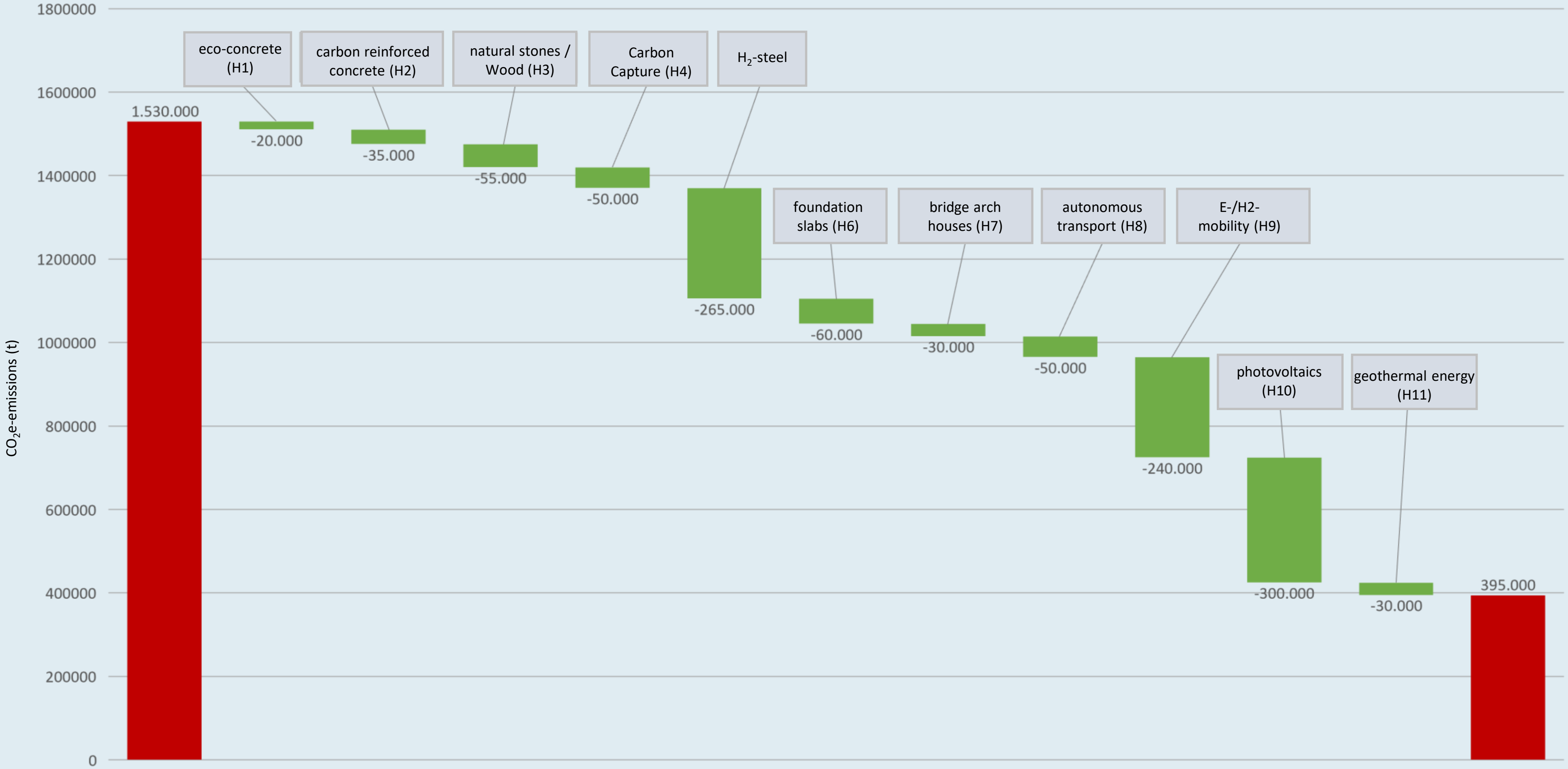
Since CO_2 is not only the most relevant of the greenhouse gases in the construction industry, but also represents the largest share of the GHG mixture, many statistics speak of CO_2 equivalent or even just CO_2 emissions, even if the values often still subsume the other greenhouse gases.

However, the concept of the Frankfurt bridges uses all available levers to reduce the potential greenhouse gas emissions

If the Frankfurt bridges were to be built overnight, using conventional building materials and without taking into account the CO_2 footprint of traffic and energy generation, the CO_2 emissions of around 1.5 million tons generated for the production of the steel and concrete required would continue to contribute to global climate change - as has often happened, or threatens to happen, with other construction projects of this magnitude, which have often been harshly criticised. However, if all available savings potential is taken into account, the GHG emissions of the Frankfurt bridges can be reduced by around three quarters - i.e. more than 1.1 million tons of CO_2!

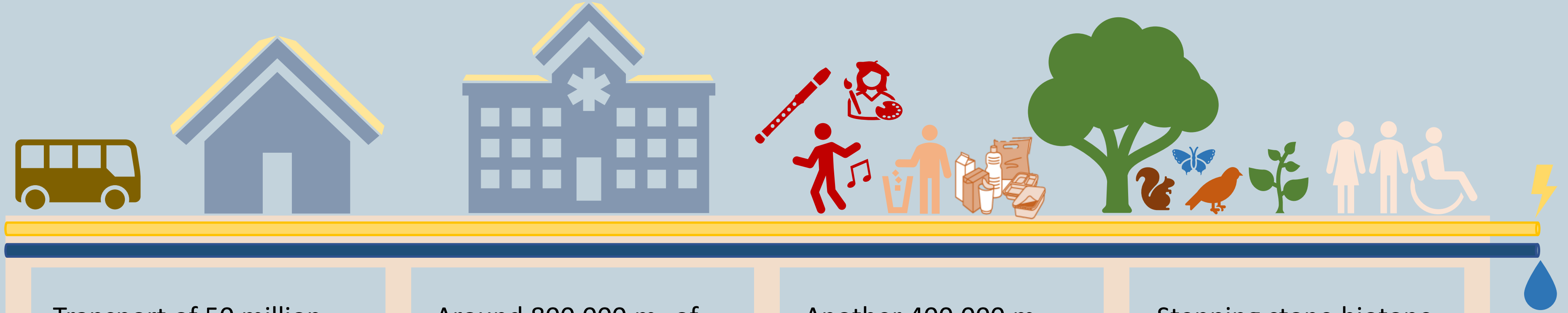


Taking into account these most different levers leads to a reduction of GHG emissions of almost 75%



Old New Territory Frankfurt

The Frankfurt bridges have another advantage over other large infrastructure projects: While other projects in Germany have only transport as their primary use, the bridges have many more functions



Transport of 50 million short trips p.a.

For comparison:
VGF Frankfurt has 190 million passengers p.a. - normal journeys.

100% electricity and heating supply for the bridge quarters through photovoltaics and ground-level geothermal energy.

Around 800,000 m_2 of space for affordable housing, i.e. over 12,000 flats with an average size of around 65 m².

For comparison:
Around 6,500 flats have been built on the Riedberg.

Another 400,000 m_2 of space for education, art, sports, organic food, organic gastronomy, social facilities etc.

Innovative concepts can be established: Hobby pop-ups, sustainable packaging world, etc.

Stepping stone biotope for hundreds of animal species

Recreation and nature experience for people in the middle of the city

Water supply for thousands of trees and over one million square metres of additional green space.

The Frankfurt bridges offer very tangible benefits for the citizens of the city of Frankfurt - but beyond that, they offer even greater benefits for all German cities, cities in Europe and cities worldwide:

Because they are a showcase of innovations for technologies and concepts to promote sustainability and humanity in the big city.

They are an area of technological innovation

Autonomous driving traffic system

Low-packaging quarters through system innovation

Neighbourhood supply through photovoltaics and geothermal energy

Bidirectional use and thus storage of renewable energy in cars

Use of waste heat from data centres and industry

Percolation concept close to the city for groundwater recharge

Partial roadway construction with low CO_2 concrete
Building construction with low CO_2 building physics

Test tracks for the optimisation of drought-resistant urban greenery and low-plastic roof/façade greenery

The bridges are also a platform for innovative social concepts

Jobs with integrated further training

Decent accommodation structures for the homeless

Connection of senior gardens with toddler gardens

Work and earning opportunities for people who have completely fallen out of the social safety net

Affordable housing close to the workplace for people with social professions

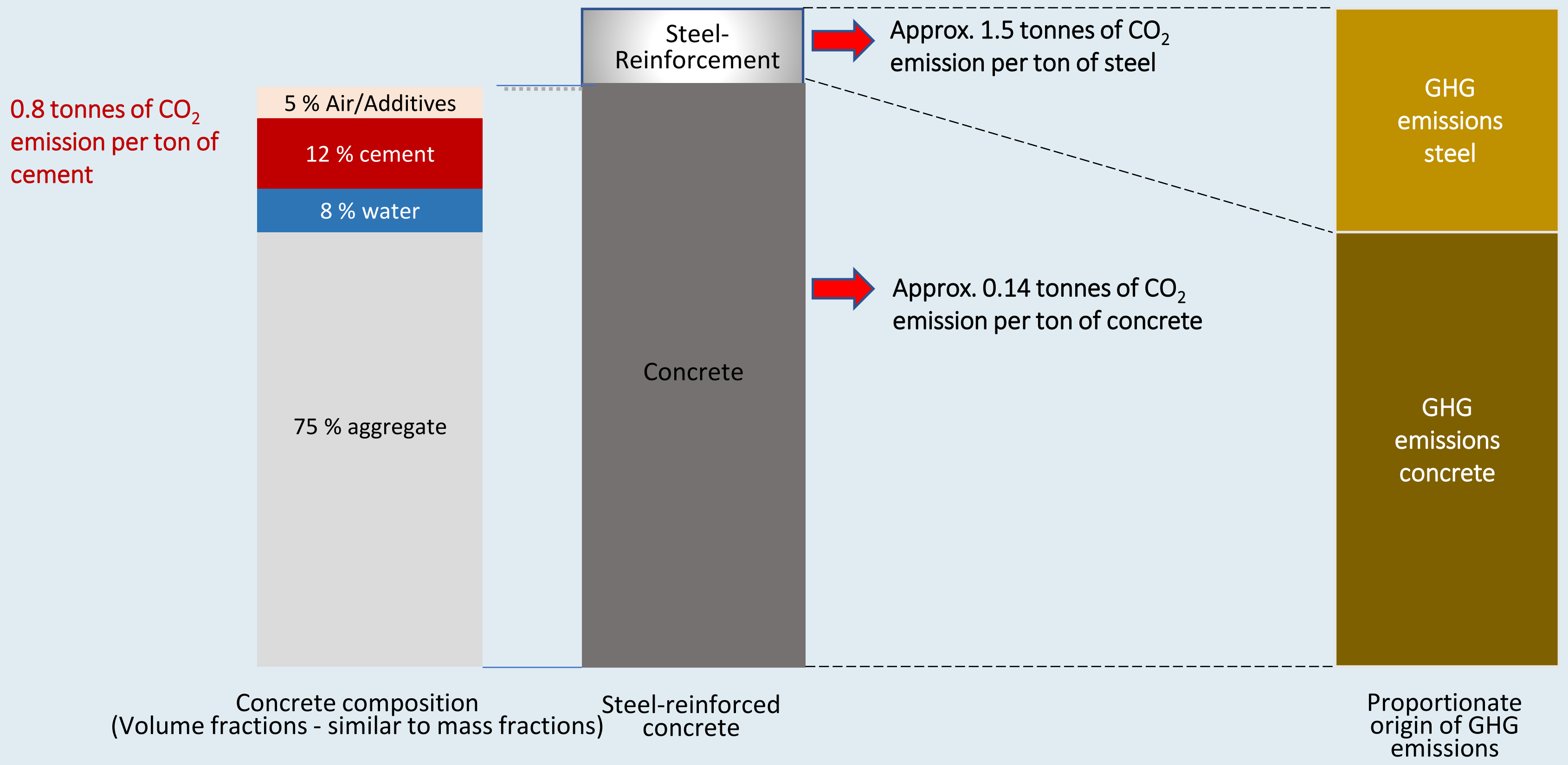
Opportunities to study without educational qualifications/credentials

Revival of craftsmanship for resource-saving building and repair culture instead of throwaway culture

The "return on investment" for all CO_2 emissions, which will have a massive impact on our climate in the future, must always be maximised - in the case of bridges, this is also achieved through their extended social function

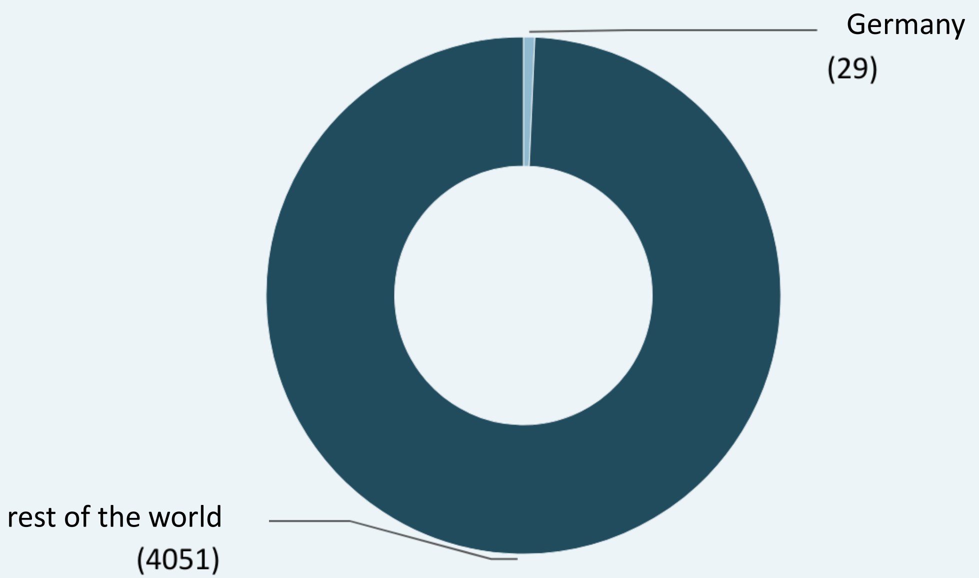
Excursus: Around 1.5 million tons of greenhouse gases for an infrastructure project made of concrete and steel -the reinforcing steel and cement in the concrete are the most important drivers of CO_2 emissions in terms of material composition

The main drivers of GHG emissions from reinforced concrete are the cement in the concrete and the steel that is either integrated into the concrete as reinforcement, i.e. for strengthening, or installed as steel columns in the infrastructure project in addition to the concrete. Unfortunately, neither component can be completely dispensed with: The steel provides stability and the cement is a kind of "glue" that causes the aggregate to stick together and not disintegrate.



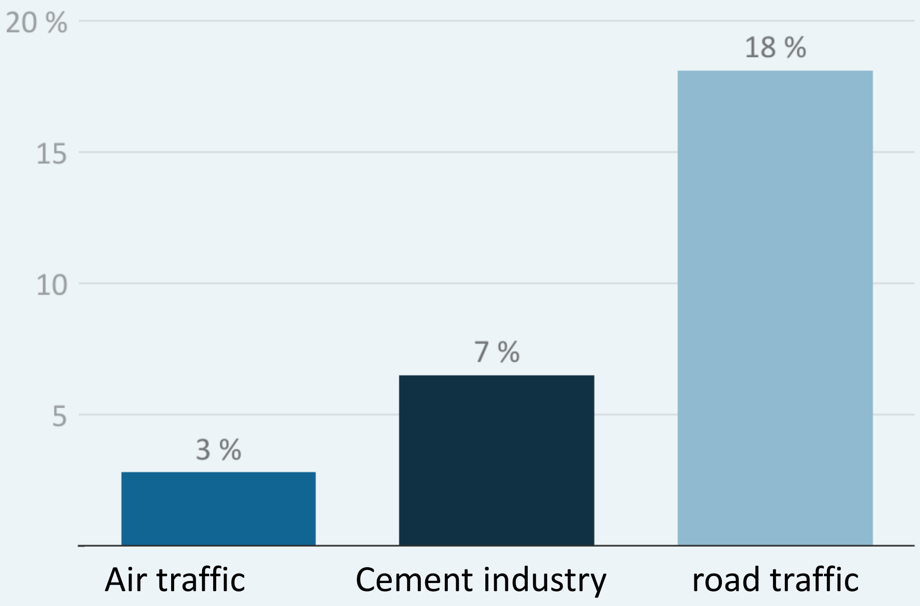
The cement industry is generally responsible for around 7 percent of global CO_2 emissions

Cement consumption 2019 in million tonnes



Quelle: VdZ, Cemnet.com, IEA • Erstellt mit Datawrapper

Share of global CO_2-emissions



Quelle: VdZ, Cemnet.com, IEA • Erstellt mit Datawrapper

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Why is the cement content in concrete so high in emissions?

Around 45 percent of cement emissions are caused by the need for heat and electricity: raw materials such as limestone, clay, sand and iron ore have to be dried and ground (the most important ingredient here is limestone, as will be explained later).

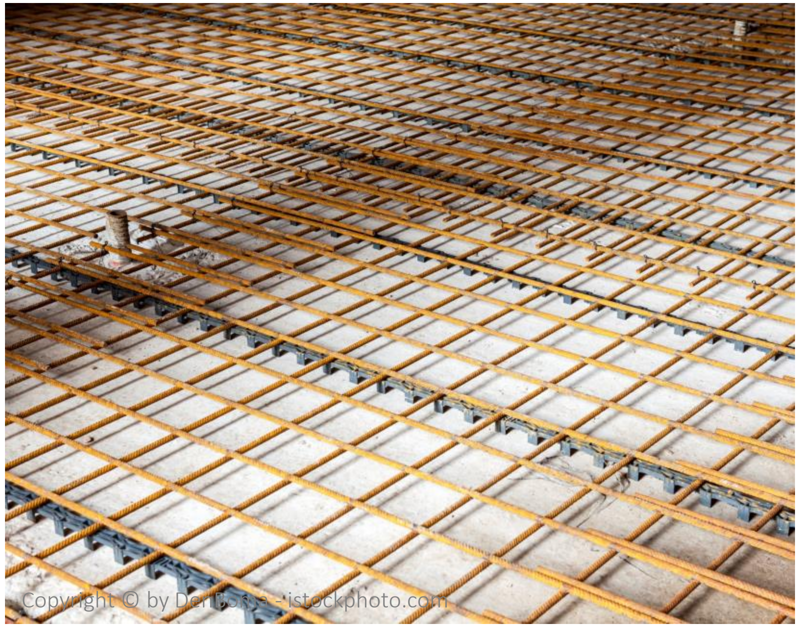
The ground raw material is then fired at 1,450 degrees Celsius - a very energy-intensive process, as one can imagine at these temperatures. But that's not all: the material burned to "clinker" must then be ground again, this time much finer than before. Only then is the clinker ready for use.

However, this energy-devouring process only releases just under half of the total CO_2 emissions. 55 percent of the emissions are not caused by the energy required for temperature and grinding, but by a chemical process during heating that produces CO_2 as a final substance - for anyone who still remembers their chemistry lessons:

Lime does not occur in nature as pure Ca (calcium), but as calcium carbonate: $CaCO_3$. However, calcium oxide is required for the production of cement clinker: CaO (as an intermediate product - from which the actually important cement constituents, namely calcium silicates, are formed). If calcium oxide is to be obtained, the formula is:

$$CaCO_3 \xrightarrow{\text{Heat}} CaO + CO_2$$

The completely transparent balancing of energy consumption and greenhouse gas emissions in relation to the benefits of buildings must become an integral part of planning approval procedures



The construction of the Frankfurt bridges would require around 50,000 cubic meters of reinforced concrete per kilometer for the entire bridge corpus, as the bridges are on average around 35 meters wide. By way of comparison, a two-track subway tunnel is about 15 meters wide and consumes an average of about 20,000 cubic meters of reinforced concrete per kilometer - about twice as much.

If the entire 60 km long section of the Frankfurt bridges were to be built in reinforced concrete (which is not planned -> *see ....*), around 3 million cubic metres of concrete would be used, along with 365,000 tons of steel.

For comparison:
According to Tagesschau, the Berlin airport has swallowed 1.3 million cubic meters of concrete.
Stuttgart 21 will also use around 3 million cubic metres of concrete - not including the four additional tunnels that are now to be added.
According to the company's own information, only 3.2 million cubic metres of concrete are estimated for the Fehmarnbelt Tunnel, with only 360,000 tons of steel - however, an additional 2.2 million tons of granite must be delivered and used for the construction section in the breakwater.

In the case of the Frankfurt bridges, all stops must be pulled out to reduce and offset the greenhouse gas emissions of the construction project - as a model for other infrastructure projects

Given their scale of construction, Frankfurt's bridges belong to the group of infrastructure projects that so often come under criticism for the exorbitant scale of their greenhouse gas emissions.

It is time that all projects of this magnitude are checked for their greenhouse gas benefit balance and that transparent, meaningful life cycle assessments are drawn up as part of planning approval procedures - which at the same time also show potential for reducing CO_2 and other greenhouse gas emissions.

Frankfurt's bridges also need to be thoroughly assessed for their GHG benefit balance: If all the stops are pulled out, the greenhouse gas emissions from the construction of the bridges can be reduced or offset by around two thirds - through substitute materials in the construction of the bridges, compensatory functions of the bridges as a structure and energy-reducing processes on the bridges.

How much are 1.5 million tons of CO_2 equivalents in relation to Frankfurt?

An adult human breathes out about 0.4 tons of CO_2 per year. A car driving 10,000 km per year emits around 1.5 t CO_2 per year. 80 beeches manage to bind about 1.0 t CO_2 per year. This means that 120 beech trees are needed to absorb the 1.5 t CO_2 emissions of a car with a combustion engine from the air.

Compensating for CO_2 emissions by planting trees becomes very difficult if one considers the city as a whole: Frankfurt's total emissions are currently estimated at around 7,000,000 t CO_2 equivalents per year, of which around 1,600,000 t CO_2 e come from vehicle traffic.

So 1.5 million tons of CO_2 equivalents is quite a lot, even if it is just a one-off and not an annual occurrence. For on the one hand, one could argue: What are around 1.5 million tons of CO_2 emissions for the construction of a project if we in Frankfurt blow 1.6 million tons of CO_2 into the air every year through our motor vehicle traffic alone? Well, this is exactly why we have a climate problem of drastic proportions, because all the CO_2 - once blown into the air - is difficult to bind again.

To really understand how dramatic every million tons of CO_2 released into the atmosphere is, you only need to go back to the beech trees: One would have to plant 800,000 beech trees at the start of construction to compensate for the CO_2 emissions of the Frankfurt bridges, so that after 100 years 1 million tons would be taken out of the air.

Unfortunately, we do not have 100 years to deal with the consequences of climate change, so at least 2,000,000 beech trees would have to be planted in order to have bound 1 million tons of CO_2 again after at least 40 years.

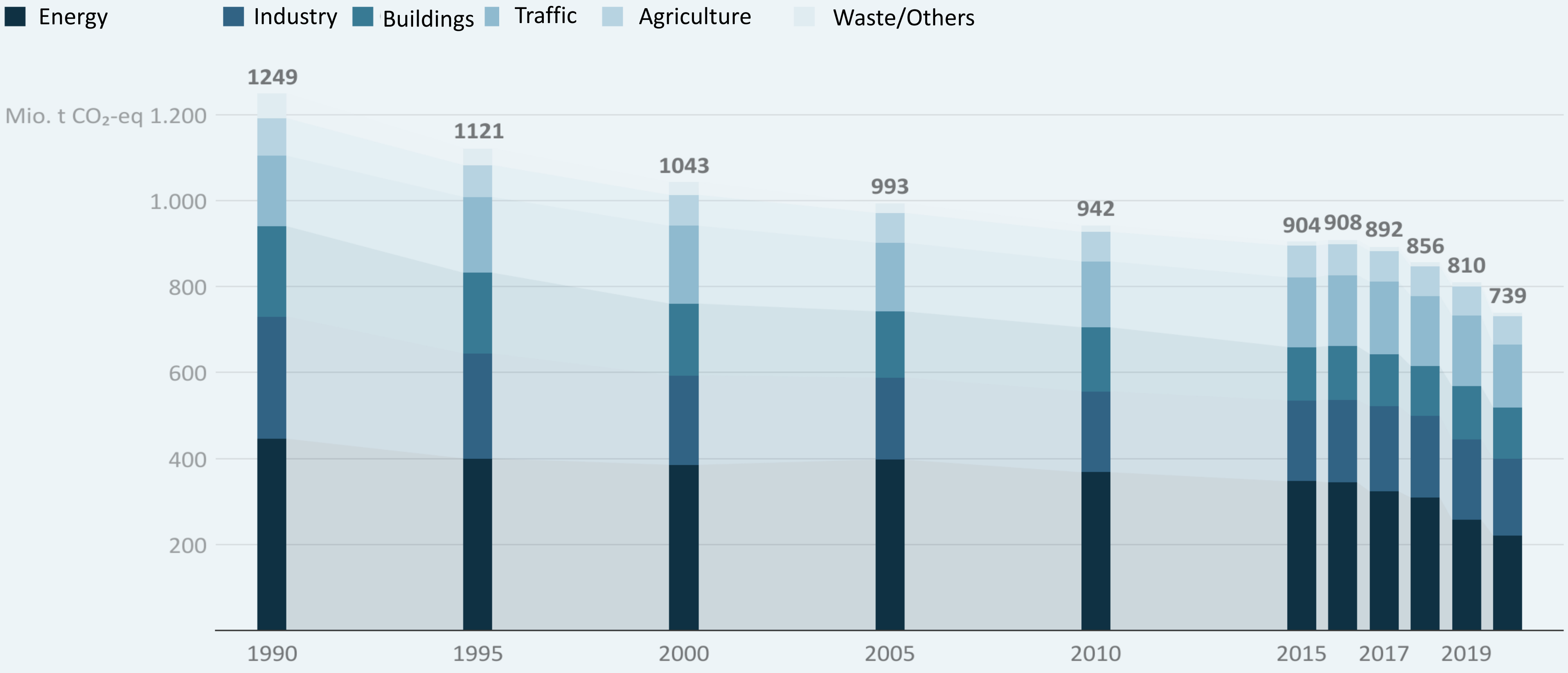
Just for comparison: Frankfurt as a whole has only 200,000 trees in its urban area. There would not be enough space in the entire Rhine-Main area for the 2 million required compensation trees.

Total CO_2 emissions Germany

How much is 1.5 million tons of CO_2 equivalents in relation to Germany?

Of the 739 million tons of greenhouse gases (CO_2 equivalents) that Germany emits per year, by far the largest proportion is CO_2 With its 7 million tons of greenhouse gases, Frankfurt contributes around one hundredth of the total German greenhouse gas emissions. GHG emissions - in line with its population of around 800,000, which also accounts for one hundredth of Germany's 80 million people.

Greenhouse Gas emissions in Germany per sector



Quelle: Umweltbundesamt • Erstellt mit Datawrapper

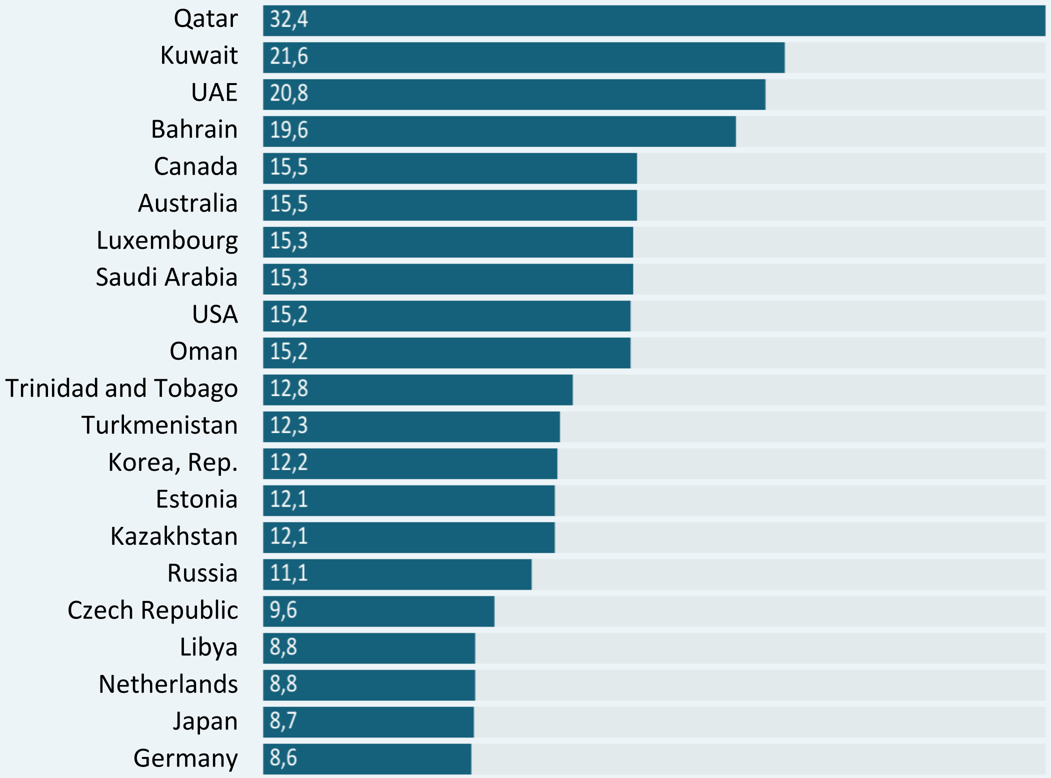
How does Germany compare to the rest of the world?

With its approximately 675 million tons of CO_2 p.a., Germany currently ranks 7th among the highest-emitting nations in the world and is responsible for approximately 1.8 % of global CO_2 emissions of around 35 billion tons of CO_2. Thus, although its share of global emissions is low, it is still above average given that Germany accounts for only 1 % of the world's population, which is also reflected in the comparison of CO_2 emissions calculated on a per capita basis.

	Nation	Amount of global CO_2-emissions in 2021
1	China	30,9 %
2	USA	13,5 %
3	India	7,3 %
4	Russia	4,7 %
5	Japan	2,9 %
6	Iran	2,0 %
7	Germany	1,8 %

Source: Statista

Yearly CO_2-emissions in 2018 (tons per capita)



Quelle: The World Bank • Erstellt mit Datawrapper

The 11-lever concept, which aims to significantly reduce CO_2 emissions from Frankfurt's bridges, is based on a combination of very different impact paths.

For example, the CO_2 balance of the bridges is improved by using building materials that are less CO_2 intensive, either naturally or due to the processes used.

On the other hand, the bridges function constructively as components of building envelopes, for which material consumption and thus CO_2 emissions are eliminated elsewhere.

In addition, the Frankfurt bridges are also the initiator of structural changes in the transport and energy sectors, which can be used to pursue a permanent and supra-regional CO_2 avoidance strategy.

For each of the 11 levers, the corresponding mode of action is explained and the CO_2 savings to be assumed in each case are quantified.

Lever 1 - Lever 2 - Lever 3

There are various approaches to improving the CO_2 balance sheet of large infrastructure projects

For example, by dispensing with conventional, high-emission building materials and switching to other materials. This can be achieved via three levers:

Lever 1 - eco-concrete: The amount of cement in concrete is reduced by innovative material concepts, so-called eco-concrete.

Lever 2 - Steel replacement: Replace the steel content in the concrete and/or the steel in the other structure with carbon fibres, bamboo, etc.

Lever 3 - Concrete replacement: You replace the concrete completely, e.g. with natural stone or wood.

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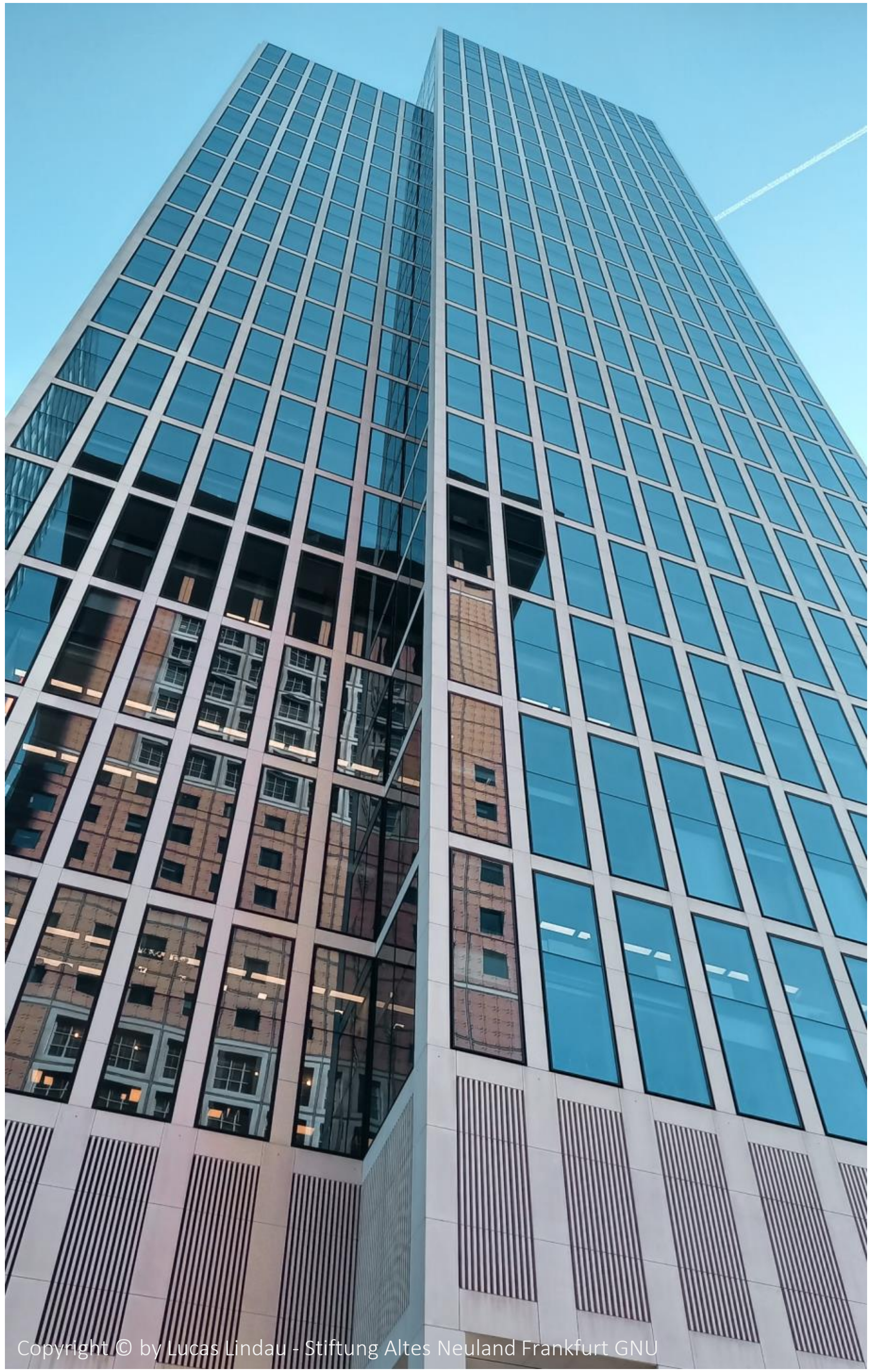
Lever 1 - Eco-concrete: Cement content in concrete is reduced by innovative material concepts

There are numerous promising research approaches to reduce the use of cement. Nevertheless, conventional cement is still used for the most part.

There is no lack of good ideas, but rather it is difficult to get the solutions found approved because their use - by definition - could not be tested for years on large buildings in advance.

The cement industry is also trying to improve its CO_2 balance, but more by working on process optimisation to save electricity and fuel for heating and not so much by using fundamentally different material mixtures.

The reason why neither research nor industry come up with completely new innovative super solutions is quite simple: the buildings produced with the help of cement must meet the highest quality requirements as well as strict safety and warranty aspects, because the stability of buildings always involves human lives.



And even if this were not the case, it should be borne in mind that the investment involved in any major construction project is extremely high - so it is not possible simply to test entire series of innovations on a trial-and-error basis.

Last but not least, it should also be taken into account that it is not enough to construct a building with innovative concrete and have it be stable and last for a few years. The real goodness of a concrete or even reinforced concrete innovation only becomes apparent after decades.

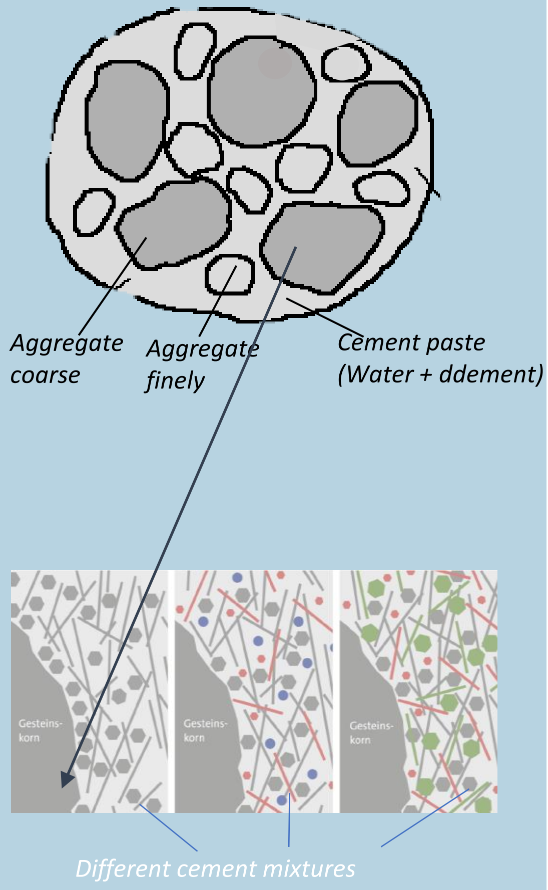
Concrete is a complex mixture: there are many points where CO_2 can be saved

The formulation change can work with substitute materials, enable changed mixing ratios - through additives or process changes - or also bring about more favourable proportions of the input materials by changing grain sizes through finer grinding processes, so that less cement is required.

The cement - mixed with water - works like an adhesive (glue) that wraps around the aggregate in the concrete mix and then hardens (crystallizes).

Option 1: Optimize the aggregate of the concrete mix so that less cement is needed to "stick":

either by using finer, denser grit, or by changing the surface of the grit, or by choosing a type of rock on which the adhesion process works well.



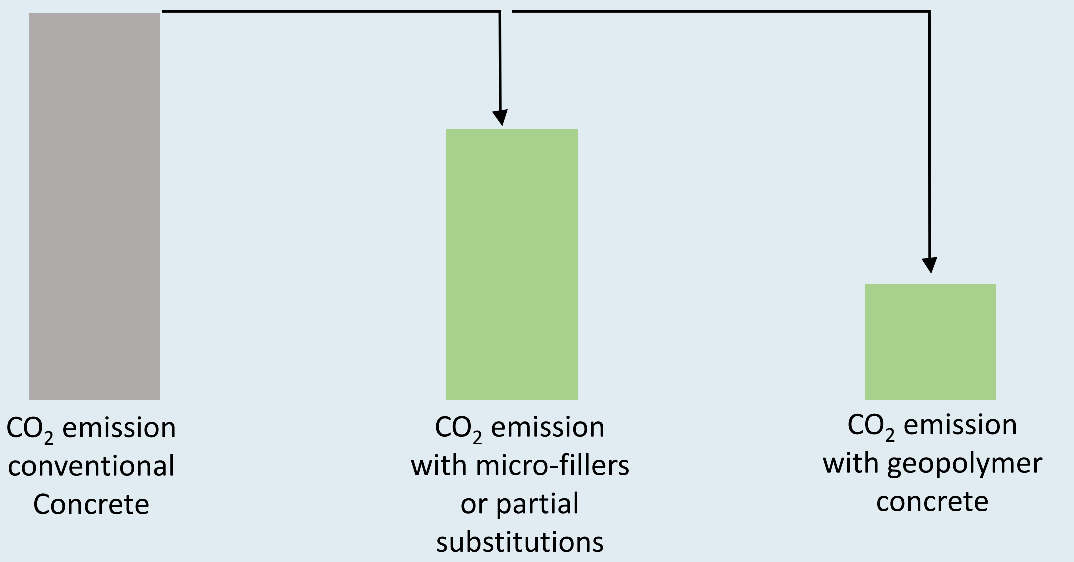
The cement itself is already a mixture, but it consists mainly of calcium silicates.

Option 2: Reduce the calcium oxide required in cement, which is responsible for 55 % of its CO_2 emissions, by adding other hydraulic binders in parts that require less lime and energy.

Possibility 3: The cement mixture with a modified composition is refined in such a way that so-called "eco-micro-fillers" can be added: finely ground materials from the region.

Depending on the research approach, new concrete technologies are expected to reduce CO_2 emissions by between 30 % and 70 %

However, in order to start building with these modern formulations worldwide, much more intensive research would have to be carried out into how durable these new concretes are in real life. Prototypical structures are missing. And this is where the Frankfurt bridges come in . . .



If only 5 of the more than 60 kilometres of track were built with eco-concrete, which produces 50% fewer emissions than conventional concrete, this would mean a saving of 20,000 tons of cement-induced CO_2

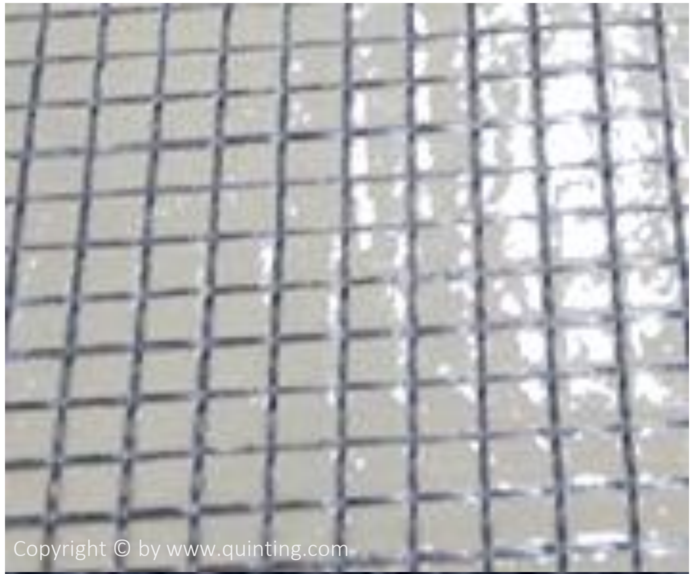
Lever 2 - Steel replacement: reinforcement made of carbon instead of steel

Carbon concrete consists of two components: Concrete and reinforcement, only in this case not steel, but carbon fibers in the form of mats and rods.

Carbon reinforcement material has two major advantages compared to steel reinforcement: It has 5 times the tensile strength of steel, so less reinforcement material is needed in comparison. In addition, carbon reinforcement is chemically inert to the stresses in construction and does not have to be protected against corrosion by a concrete cover several centimetres thick like steel reinforcement.

For components made of carbon concrete, material can thus be saved and they can be made significantly thinner. The CO_2 saving when using carbon reinforcement instead of steel is estimated at 30 %.

Of the 1,500,000 tons of CO_2 emissions from Frankfurt's bridges, around one third, i.e. 525,000 tons, come from steel. If one fifth of this is replaced by carbon, then the 105,000 tons of CO_2 emissions are reduced by around **35,000 tons** - not including the indirect reduction through reduced concrete consumption.



If one fifth of the steel is replaced by carbon reinforcement, at least 35,000 tons of CO_2 can be saved

Lever 3 - Concrete replacement with regional natural stone or wood

Instead of reinforced concrete, some sections of the Frankfurt bridges can also be built using regional natural stone or wood.

Where the bridges pass over old trees, viaduct-like ashlar structures or masonry viaducts could be a solution: they could wind their way on slender columns as a five-meter-wide ribbon through the Senckenberg complex, for example. Suitable natural stones for such ashlar structures are red Main sandstone and Taunus quartzite, which are quarried in regional quarries near Frankfurt. The red Main sandstone in particular is not only suitable for artistic designs, but also as a protective covering for the concrete of the bridges to protect it from corrosion.

The Master Craftsman Academy is supposed to provide the professional capacity for this, because hardly anyone can do it today. But not only the craftsmen, also the structural engineers are in demand: After all, many buildings have lasted for centuries, but they cannot be calculated with modern post-war DIN standards.

The rediscovery of traditional construction methods with low CO_2 materials will therefore be a challenge. The use of wood in construction is desirable anyway as a renewable raw material - but in the case of the Frankfurt bridges it is only possible in certain sections: suitable here are primarily stretches on which there are no buildings, but only footpaths and walkways, as this entails a significantly lower load.

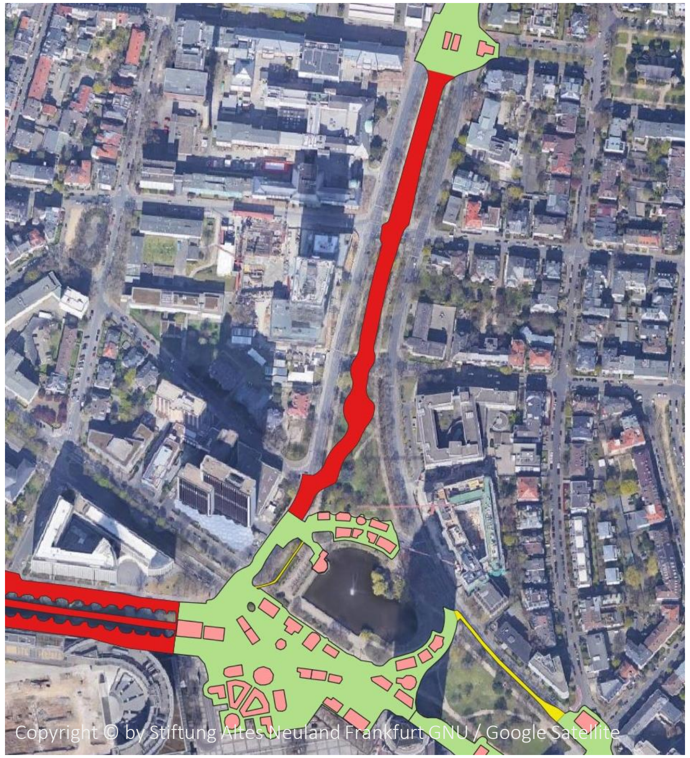
Replacing around 1.5 km of the concrete bridge sections with natural stone and 4.5 km with wood results in a saving of 55,000 tons of CO_2

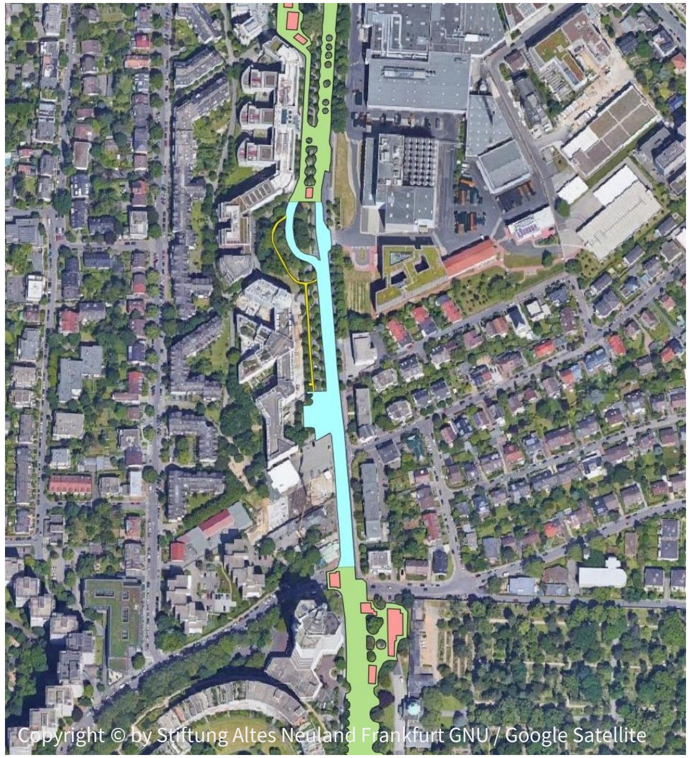
The selection of sections for construction with natural stone, wood or even eco-concrete is primarily done where there are no buildings on the bridges

Natural stone can be used to span old tall trees where large massive columns can be founded. In addition, bridge sections on high "stilts" look more beautiful, if they are masonry viaduct style.

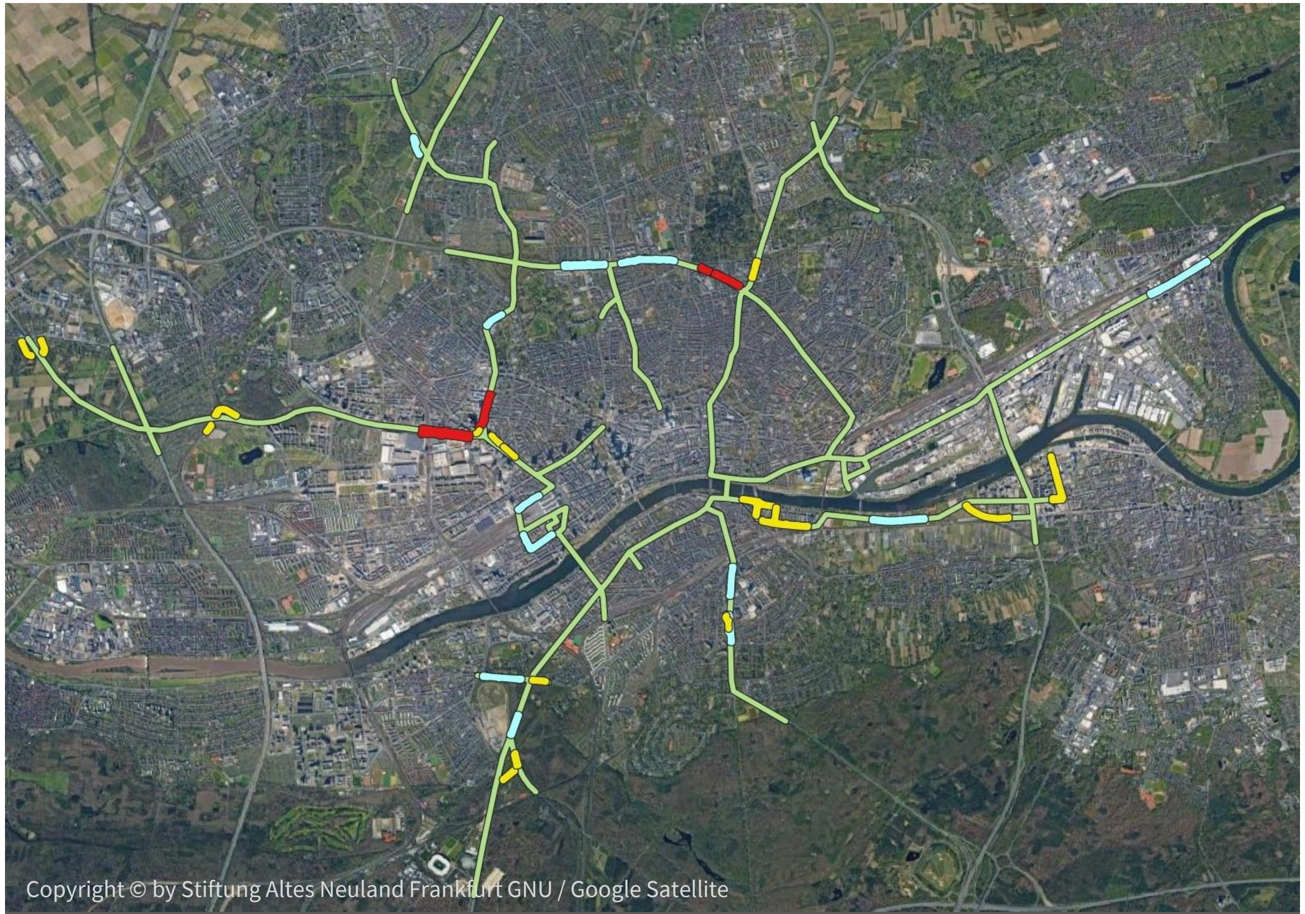
Timber is used in places where there are no carriageways on the route or where there are carriageways but they are not heavily frequented. Compared to natural stone, wooden structures have the advantage that they can span wide sections even without high wall arches.

Eco-concrete can be used in exactly the same way as conventional concrete, but it is also only used in places where there are no buildings on the bridges, as there is still no long-term experience with these materials and in the event of renovation in a few decades no other structures would be affected.





At several points on the bridges there are sections that are suitable for construction using materials other than conventional concrete



Suitable for the following building materials: Eco-concrete | Brick or natural stone masonry | Wood

Many stretches of the Frankfurt bridges are not built on with houses, but serve as traffic links, walking paths or green spaces.

These areas are suitable as test sections where the bridge is built from eco-concrete, which is mature but has not yet been tested on a large scale and for extended periods of time.

The areas must be monitored and checked by research and industry, and regular tests and evaluations must be carried out to ensure that any need for remediation is identified at an early stage. If there are no buildings on them, then potential remediation, although tedious, can be carried out more quickly and without too much effort.

Alternatively, the use of brick or natural stone masonry or timber should be considered on such sections.

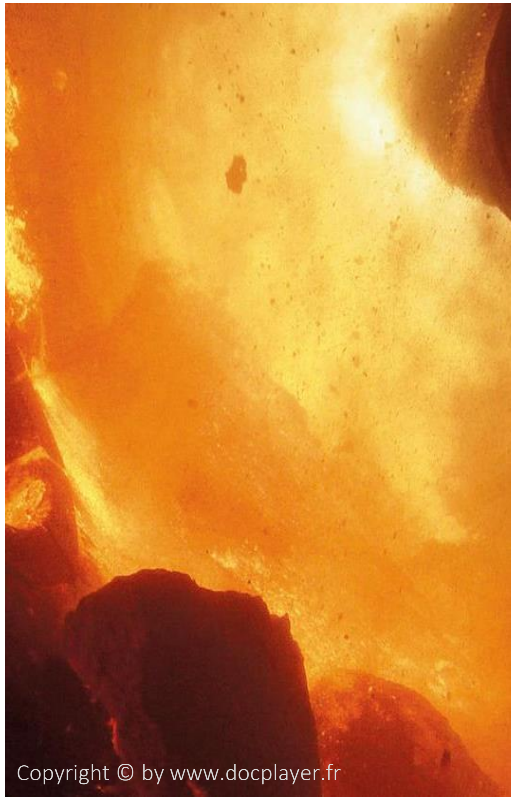
Lever 4 - Lever 5

In the future, however, new processes in the cement and steel industries will also significantly improve the CO_2 balance of conventional building materials

Green hydrogen plays a key role here, making it possible to greatly reduce the release of the climate-damaging greenhouse gas into the atmosphere. As such innovative processes are increasingly coming into focus in both cement and steel production, two further levers are being added to the CO_2 balance sheet of the Frankfurt bridges.

Lever 4 Concrete carbon capture in cement production
Capturing and reusing the CO_2 produced in cement production makes it possible to use more climate-friendly concretes for Frankfurt's bridges.

Lever 5 Steel - CO_2 savings in steel production with the aid of hydrogen: CO_2 emissions for steel can be drastically reduced through an innovative process for substituting coke with hydrogen as a reaction partner in the extraction of iron from iron ore.



Lever 4 - Carbon capture in cement production

In cement production, the actual production process is preceded by an electrolysis process in which water is split into oxygen and hydrogen with the help of wind or solar energy. The pure oxygen can then be fed to the rotary kiln instead of "normal" air (oxyfuel). This has the advantage that the CO_2 produced during the combustion process remains free of impurities and the greenhouse gas can be captured (carbon capture). Subsequently, the captured CO_2 is converted together with the hydrogen from electrolysis into other raw materials, such as synthetic fuels. In this way, the climate impact of a large proportion of the CO_2 emissions generated in the cement industry can be prevented. Since the process described is currently being tested on a large scale and its increasing implementation in the manufacturing process can be assumed for the next few years, the Frankfurt bridges will also benefit from this.

Visualization of the process

A conservative estimate assumes a saving of 5 percent of CO_2 emissions, i.e. 50,000 tons of CO_2 through carbon capture

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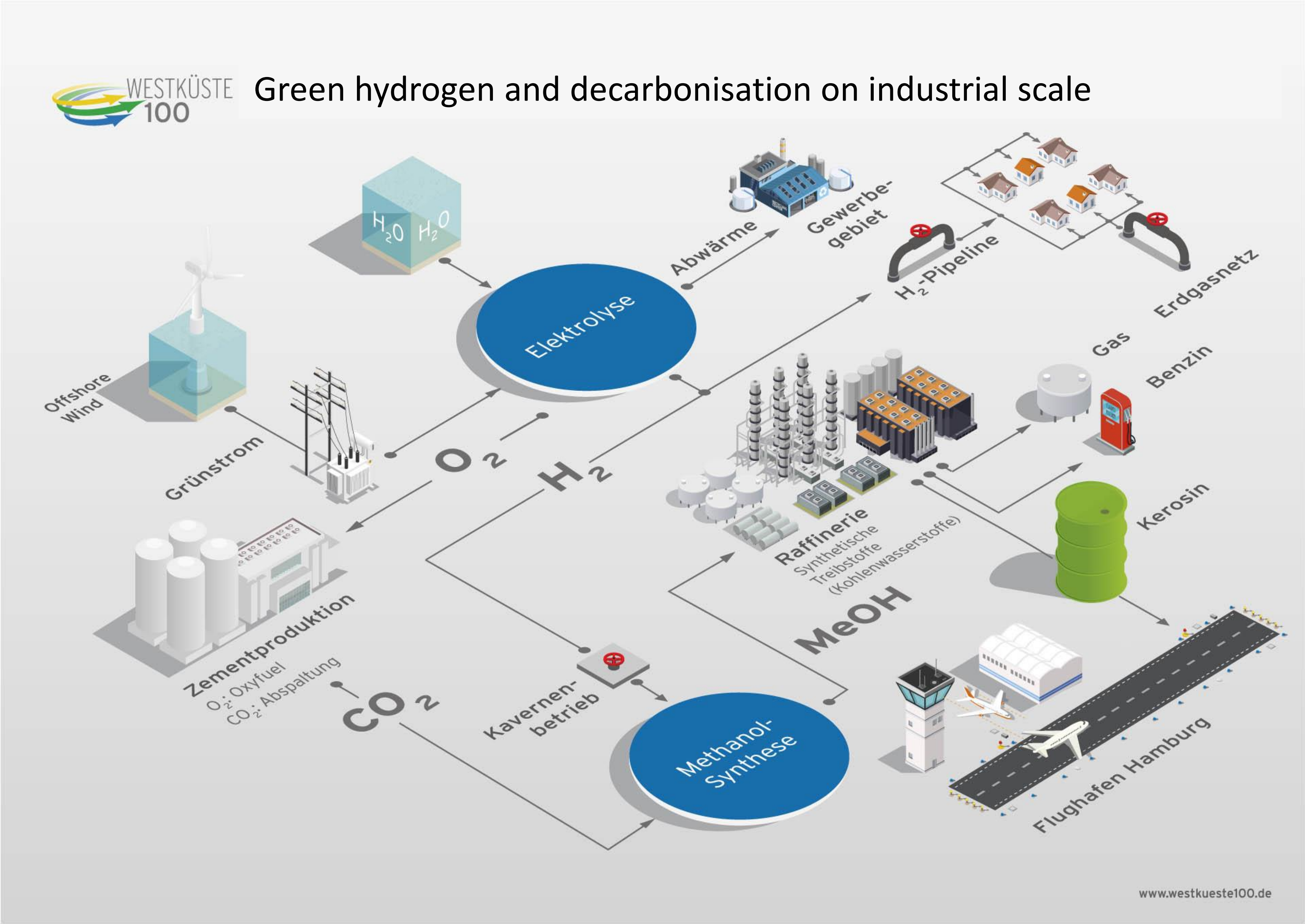
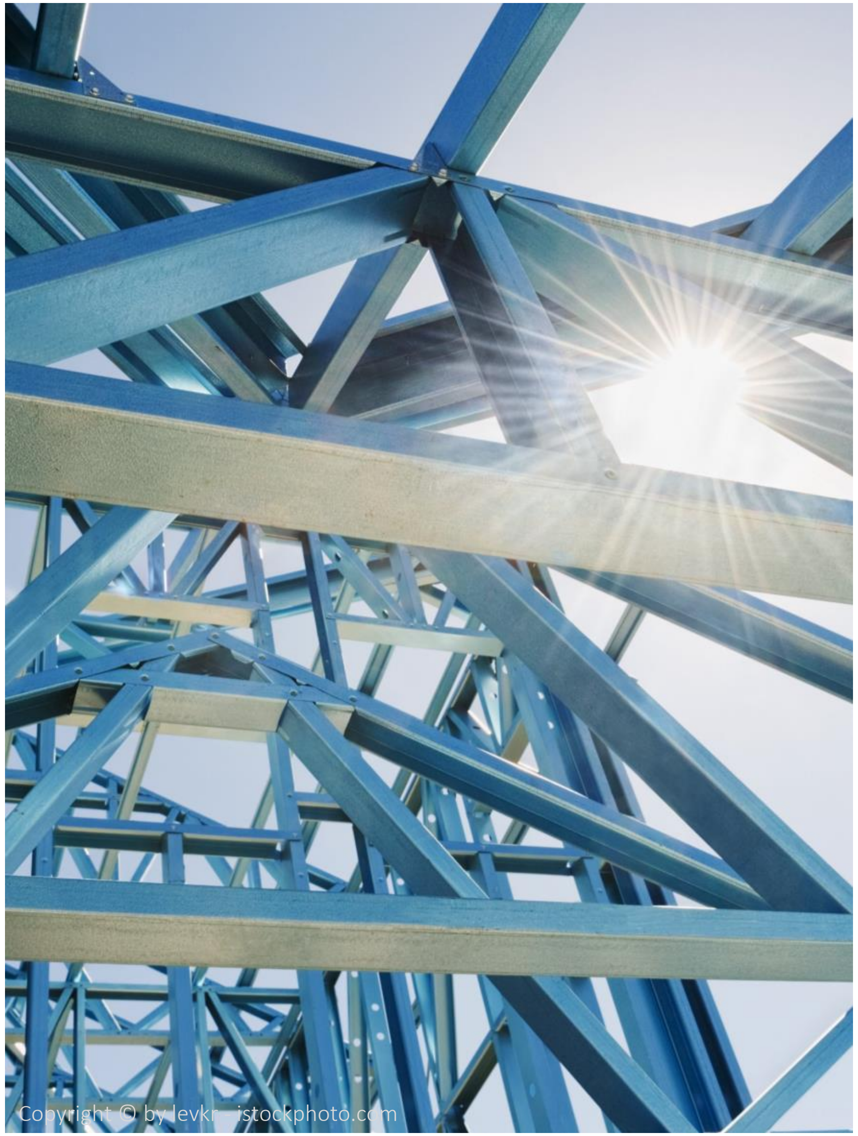


Lever 5 - CO_2 savings in steel production with the aid of hydrogen

The savings potential for CO_2 emissions is particularly large in steel production. The current blast furnace route, in which the iron ore is reduced to pig iron with the aid of coal or coke and enormous quantities of greenhouse gases are released, can be replaced in the near future by a new hydrogen-based process. Here, too, green hydrogen is first generated by means of electrolysis, which can then be used to extract the iron from the iron ore in a direct reduction plant before it is processed into crude steel in an electric arc.

By avoiding the use of fossil fuels, up to 95 % of CO_2 emissions can be directly avoided. If the entire steel requirements of Frankfurt's bridges were covered by steel produced in this way, around 500,000 tons of CO_2 -equivalent GHG emissions could be saved.

Visualisation of the process



Due to the strong demand and corresponding expected bottlenecks in the supply of steel, a saving of 50 percent, i.e. around 265,000 tons of CO_2, is assumed for the Frankfurt bridges

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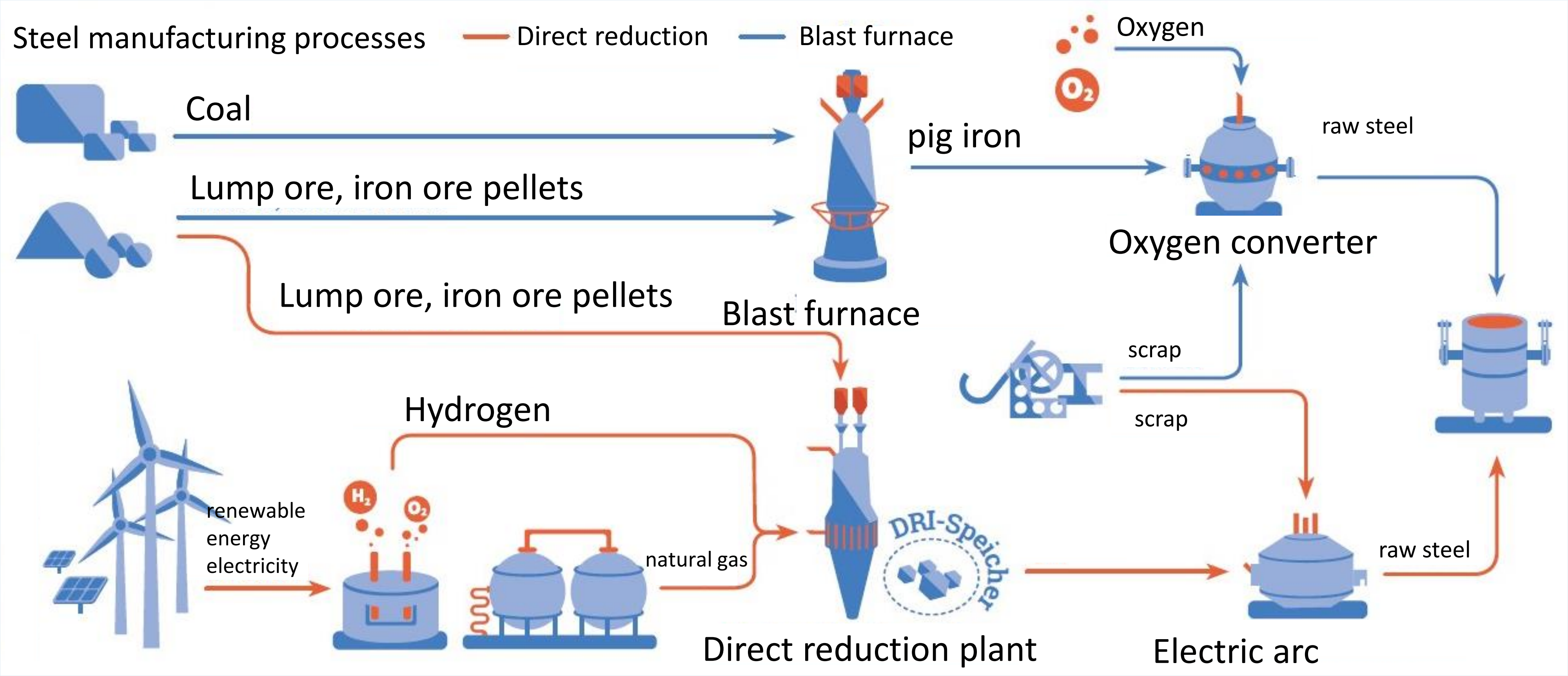


Lever 6 - Lever 7
However, the possibilities for reducing CO_2 emissions extend beyond the materials used in the body of the bridge

Frankfurt's bridges also create a lot of potential for indirectly reducing CO_2 emissions. For example, the concrete and steel used fulfill several structural functions at the same time, for which construction material does not have to be used again elsewhere.

Lever 6 - Bridge corpus as foundation slab: The concrete and steel used assume the function of foundation slabs for the buildings on the bridges, so that new buildings can be dispensed with elsewhere.

Lever 7 - Bridge Arch Buildings: In the distant future, the Frankfurt bridges can take over the function of the supporting structure for bridge arch buildings below it, which means that less building material is needed for these buildings.

Lever 6 - Bridge body as foundation plate:

The bridge corpus can be used for a variety of structural purposes. This includes many of the functions and uses of the Frankfurt bridges already presented.

Finally, the bridges create a new piece of Frankfurt, with an area of around 2 million square metres, on which buildings can be constructed without having to make foundation slabs for them.

The buildings on the bridges have a total construction area of around 450,000 square metres.

For this, around 180,000 cubic metres of concrete (approx. 450,000 tons of concrete) would have to be placed on the greenfield site, which would be eliminated by using the bridge corpus as a foundation slab.

Assuming that each tonne of concrete produced generates around 135 kg of CO_2, the foundation slabs saved can compensate for a total of 60,000 tons of CO_2

Lever 7 - Bridge Arch Houses:

In addition, for a period of 100 years or more, a further function must be provided for and planned in structurally from the outset:

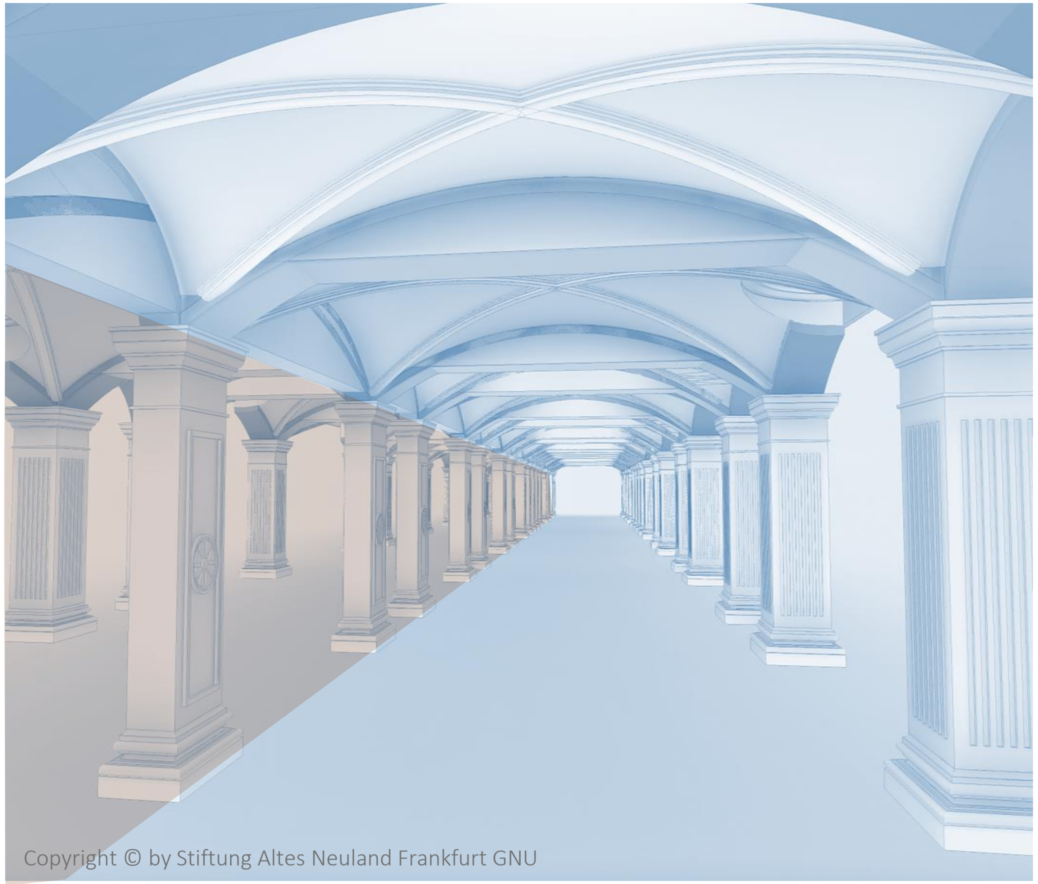
With massive reductions in traffic through optimized autonomous driving traffic systems, a city's formerly four- or six-lane entry roads can be reduced to two vehicle lanes and two bike lanes.

The space freed up under bridges (two or more lanes, 6 or more metres wide) can be used in places by converting it into living space:

This living space then already has supporting columns (the supports of the bridge), possibly already wall areas (if there was a bridge-bearing central wall on the median strip before) and a "roof" (the bridge corpus).

Frankfurt's bridges could take on yet another function in 50 to 100 years: Creating rows of buildings under the bridges

Most of Frankfurt's bridges run over major four- or six-lane traffic roads. If a city were to have exclusively autonomously controlled traffic, the number of all vehicles could be significantly reduced (some forecasts expect up to 80 % fewer vehicles). Some lanes could then be eliminated, and space would be freed up under the bridges that could be converted into building space, since supports and roofs are already in place.



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In half a century (or more), half of the body of many of Frankfurt's bridges can be used to build apartments, cafés, or shops into them

Educational facilities, nurseries or office space can also be built under the bridges when the number of vehicles has drastically decreased in a couple of decades

Since all the bridge supports are geothermally activated, the "buildings" under the bridges can also be heated in an energy-efficient manner. Due to the connections to the supply centers, which were installed from the beginning and are planned every few hundred meters along the bridge, the supply with electricity, drinking water, etc. is already available.

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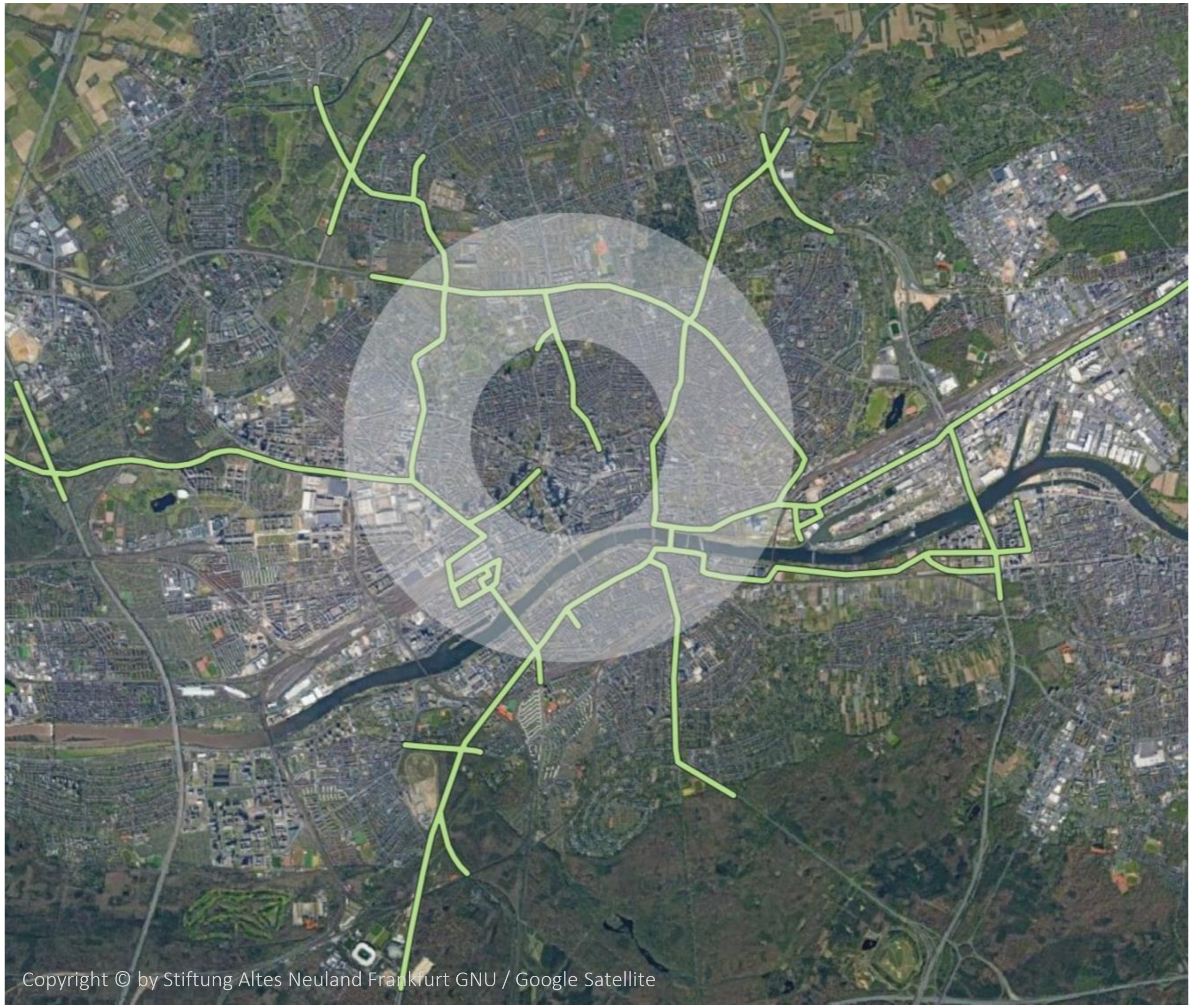
84,000 square meters of building space can be created under the bridges for future generations - without additional amounts of concrete or steel



The areas with potential for bridge arch buildings are primarily along the ring road and the beginnings of the outer arms - but you don't know what the bridge network will look like in 50 years: There may also be further opportunities for fixtures under the bridges elsewhere.

It is estimated in the planning that around 20 % of the line could be built half-way underneath: i.e. up to 12 kilometres of continuous building lines with a depth of around 7 metres would be created.

This means that around 84,000 additional square metres of building space can be created in this way, for which the load-bearing structure is already in place thanks to the bridges, so that their construction or expansion hardly requires any concrete or steel.

The potential of the bridge arch houses will only become noticeable in the CO_2 balance sheet of the Frankfurt bridges with a delay

Due to the long time horizon, the estimation of CO_2 savings for the bridge arch houses can only be made roughly:

The bridge corpus, which serves as the ceiling of the bridge arch houses, has a thickness of 0.5 m. With a total area of 84,000 square meters, the volume of the reinforced concrete serving as the slab thus amounts to 42,000 cubic meters.

On the other hand, greater concessions will have to be made for the piers. This is because the approximately 3,000 columns that would be affected by the bridge arch installation are oversized in terms of their dimensions for the intended use of the later bridge arch houses. Therefore, if the material of only 1,000 columns is taken into account, about 20,000 cubic meters of reinforced concrete are added.

More than 60,000 cubic meters of reinforced concrete could thus be put to dual use in the distant future.

Since just under 0.5 t of CO_2 is produced for every cubic metre of reinforced concrete, a further 30,000 t of CO_2 can be assumed for the long-term option of the bridge arch houses, which can be avoided in subsequent construction projects

Lever 8
On the bridge as a second level through the city a modern environmentally friendly traffic concept of the future can be realized

The load-bearing function of bridges for autonomous traffic comes into its own.

Lever 8 - Optimised traffic flow on the "second level“

The bridges carry "second-level" traffic that travels on a proprietary route. This makes an efficient autonomous driving system in the middle of the city possible for the first time.

Lever 8 - Optimised traffic flow on the "second level“

Traffic on Frankfurt's bridges in vintage look and with luxurious interiors will significantly increase the acceptance of the use of non-owned passenger cars. Autonomously driving traffic will also make it much more attractive to do without one's own private vehicle, as all the worry and expense of owning one's own car will be eliminated by this form of "chauffeur-driven transport". Studies show that 90 percent fewer private cars are needed for complete coverage through car sharing. A centrally controlled system of luxurious autonomously driving vehicles will thus also gradually lead to comfortable "car sharing" on the roads.

The resulting CO_2 savings from a reduction in new vehicles to be produced in Germany can only be estimated within the framework of the feasibility study. More precise simulations of this must be carried out as part of the planning phase for the Frankfurt bridges. The Frankfurt bridges are expected to handle around 50 million passenger journeys per year.

The estimate of the effect of a reduction in the number of new vehicles to be produced in Germany was set extremely conservatively at 50,000 tons of CO_2 savings

Lever 9
The number of refuelling options for clean propulsion energy is significantly increased by photovoltaic electricity production on the Frankfurt bridges

This is because the Frankfurt bridges collect solar energy on a large scale, which is made available to vehicle owners in Frankfurt in the form of electricity or after conversion into hydrogen.

Lever 9 - Accelerating the move away from the internal combustion engine

If, thanks to a dense network of inexpensive refuelling options, more vehicle owners in Frankfurt switch to clean drive energy earlier than they had planned, this will mean an immediate saving in vehicle-related CO_2 emissions.

Lever 9 - Accelerating the move away from the internal combustion engine

A car with an internal combustion engine that travels 10,000 kilometres per year currently emits an average of around 1.5 tons of CO_2 per year. The nationwide target is to stop registering cars with internal combustion engines by 2030. The penetration rate of cars with hydrogen or electric drives is therefore likely to rise to up to 80 percent in the next 20 years.

After completion of the Frankfurt bridges in about 15-20 years, there will be at least seven more hydrogen filling stations close to the city centre and charging stations at all bridge pillars near the car parks, providing a very attractive additional range of filling options for hydrogen and e-cars.

Conservatively estimated, this should lead to an increase in the penetration rate of vehicles with clean drive energy of around 10 percent. With 386,000 vehicles in Frankfurt (as of 2020) and 400,000 commuter vehicles, approximately 78,000 vehicles could switch to clean energy up to three years earlier.

If, due to cheap and widespread refuelling options, 80,000 owners convert their vehicles to clean propulsion energy around two years earlier than planned, this will lead to a saving of around 240,000 tons of CO_2

Lever 10
The photovoltaic modules installed on Frankfurt's bridges can substitute electricity generated from fossil fuels

The urban energy turnaround can be realized on Frankfurt's bridges:
From photovoltaics to solar thermal and waste heat to geothermal energy: the city's complete potential for renewable energies can be used and optimally balanced. This will significantly reduce or replace CO_2 emissions from coal and gas combustion over many years.

Lever 10 - Photovoltaics

The bridges are an exposed suspension surface for photovoltaics. The body of the infrastructure project is used to generate renewable energy. In the case of the bridges, the surfaces (aesthetically beautiful or invisible) serve as a photovoltaic park. In addition, due to their grid structure, they can also receive solar power generated along the bridges and transmit it to consumers.

Lever 10 - Renewable energy from photovoltaic modules

135 GWh of electricity can be generated annually by photovoltaic modules on the body of the bridge. Of this, only 115 GWh of electricity is consumed on the bridges themselves. This leaves 20 GWh of residual energy available to the city in the form of electricity.

On the city side, the production of 135 GWh of electricity p.a. is substituted, for the generation of which around 37,000 tons of hard coal or 25 million cubic metres of natural gas are burnt in Mainova's current power plants.

Quarter supply by quarter photovoltaics is developed pioneering on the bridges

The complete variety of photovoltaic systems, including (still) expensive systems from research and development, is presented at the bridges like in a "showcase of innovations" for other potential users and further tested in its long-term effect. The bridges are thus an application platform for the further development of the world of photovoltaics.

Another innovative feature is the optimized control of all energy components in the bridge district by means of an integrated, comprehensive AI system: The district is thus self-sufficient and virtually follows the functional principle familiar from smart homes on a smaller scale. This also serves as a model for other districts.

Frankfurt aims to become almost CO_2 neutral by 2050 and to reduce electricity generation through the burning of fossil fuels as far as possible. The annual energy production from the renewable energy of the Frankfurt bridges should make a substitution contribution to this over a period of at least 5 years.

If Mainova's combustion processes for the production of 135 GWh of electricity p.a. are eliminated or substituted by the generation of renewable energy at the bridge corpus, this corresponds to a CO_2 saving of 60,000 tons p.a. After just 5 years, the total CO_2 savings will amount to 300,000 tons

Lever 11

With the help of the pillars of the Frankfurt bridges, geothermal heating energy can be used as a substitute for energy from fossil fuels

This will reduce CO_2 emissions over many years, which come from burning gas to heat homes.

Lever 11 - Geothermal energy

A large part of the 15,000 pillars of Frankfurt's bridges are used to generate energy by activating them geothermally, which allows them to heat and cool the buildings on the bridges.

Lever 11 - Heating and cooling with the help of geothermal energy

The use of near-surface geothermal energy is planned directly during the construction of the bridge: geothermal probes are inserted into the 15,000 piers of the bridges during construction. In principle, the subsequent integration of geothermal probes into a structure involves extremely high costs, which is why heating with fossil fuels will be important for much longer than coal or gas-fired power generation.

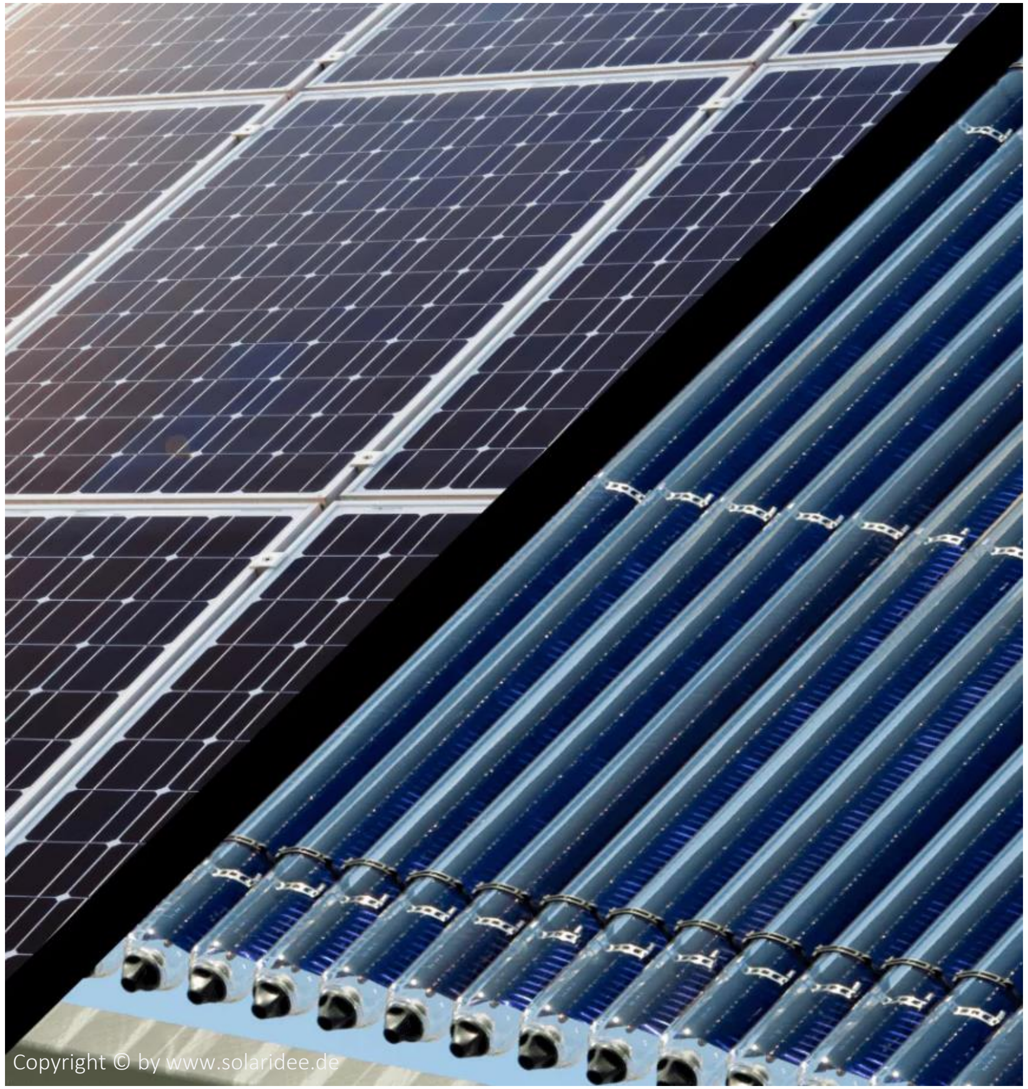
In addition to the use of near-surface geothermal energy, the waste heat from the data centres to the right and left of the bridges is used by the geothermal pipe system connecting the piers.

The consistent equipment of all buildings on the bridges with surface heating and cooling ceilings fulfils the prerequisite for the use of this low-temperature energy.

Near-surface geothermal energy can be used for heating and cooling

In winter, the pipes in the earth piles transport their brine liquid upwards, which is up to 14 degrees warmer than the outside temperature. The brine fluid transfers its heat from the ground to a heat exchanger, where a heat pump can be used to raise the heating water for buildings to a supply temperature of 50 degrees.

To prevent the soil from cooling down when heat is extracted each winter, the soil around the piles must be thermally "regenerated" in summer: This is done by reversing the process described above: The brine fluid flows through solar panels on surfaces exposed to the sun in the summer, returning to the ground warmed. This allows the soil to recover from the heat extraction during the winter period and prepares it for the next winter.



Thus, on the part of the city, the production of 15 GWh of thermal energy p.a. is substituted by natural gas. The substituted quantity of natural gas causes CO_2 emissions of around 3,000 t p.a. when burned. After 10 years, the CO_2 savings amount to a total of 30,000 tons

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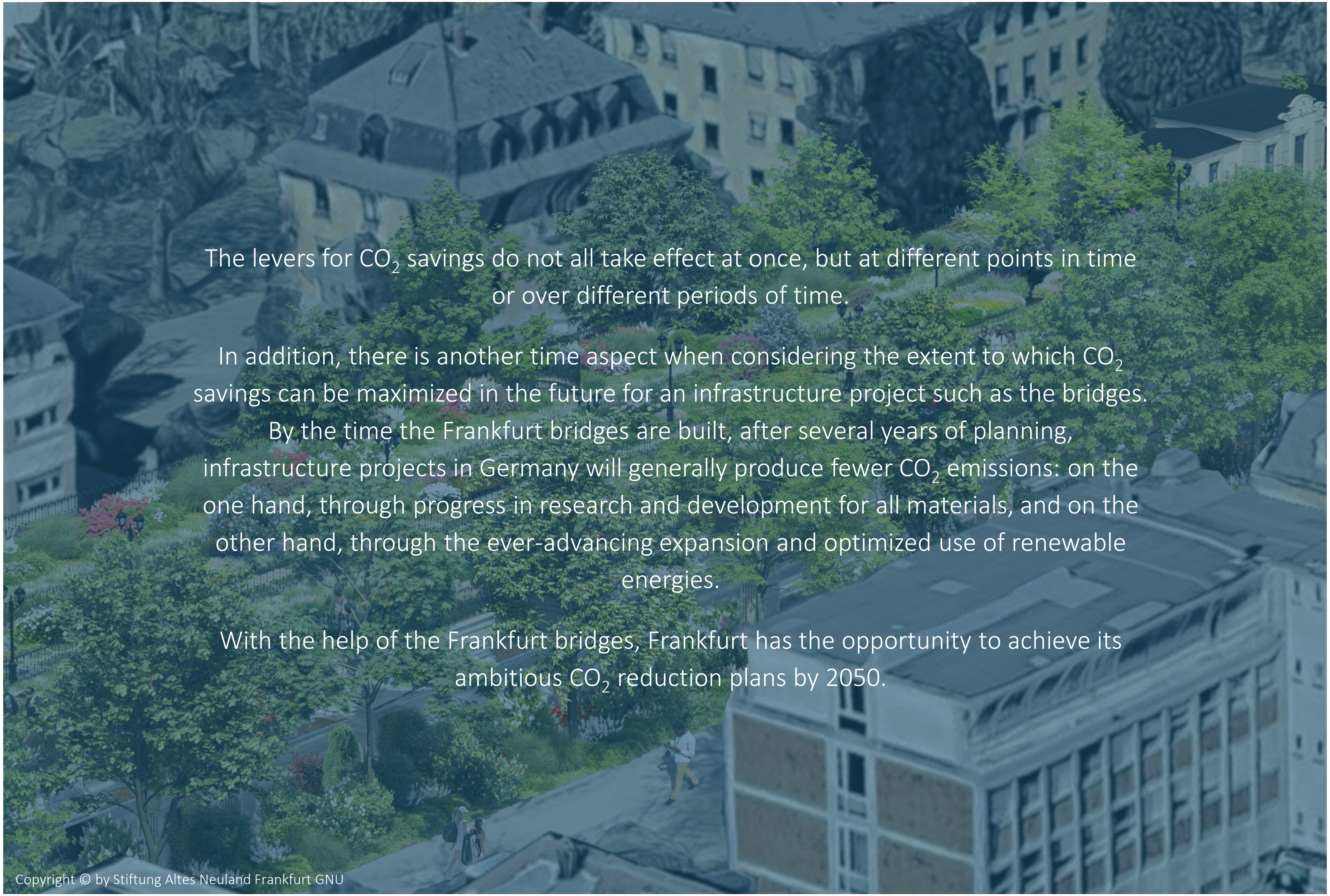
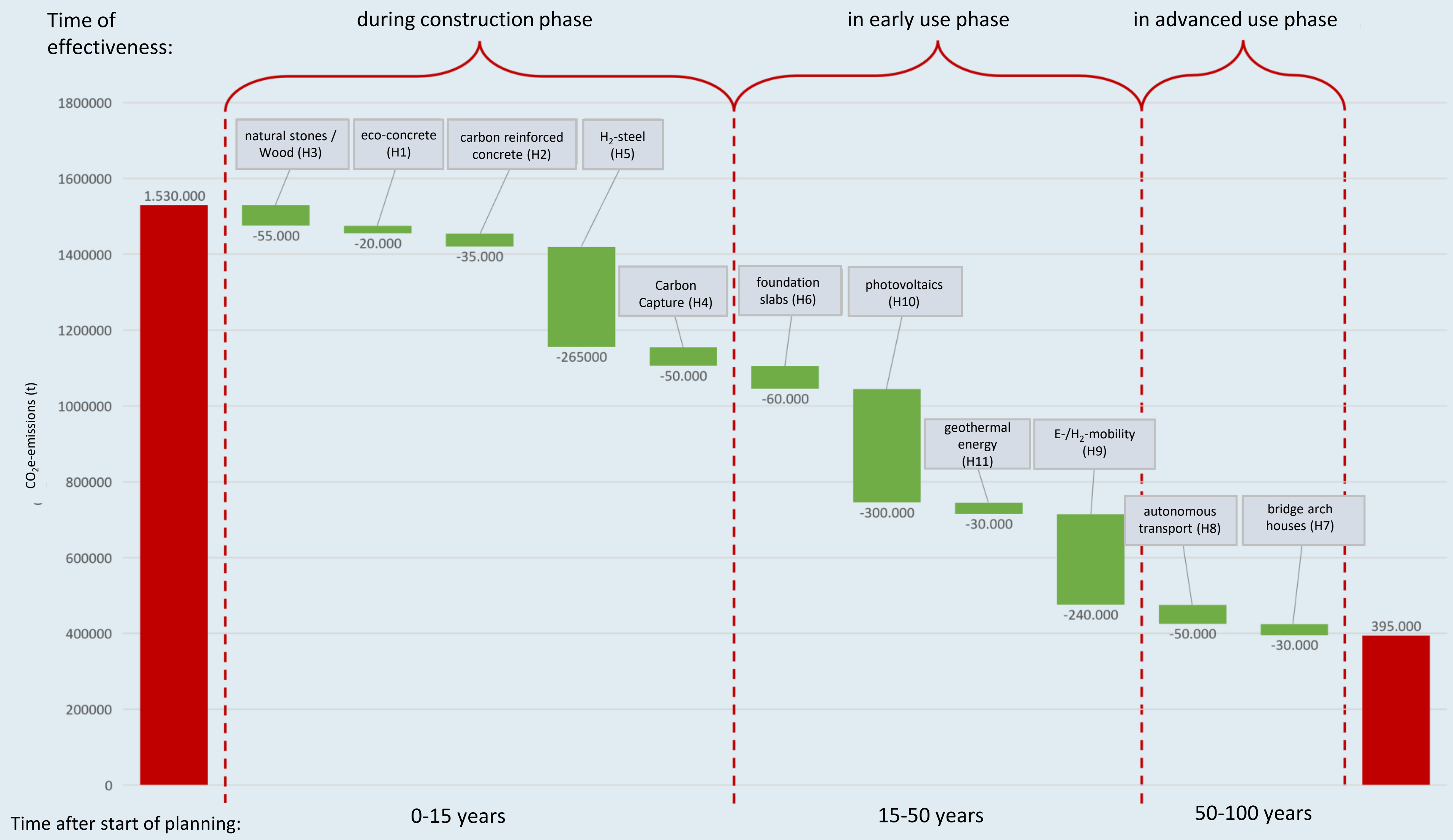


The levers for CO_2 savings do not all take effect at once, but at different points in time or over different periods of time.

In addition, there is another time aspect when considering the extent to which CO_2 savings can be maximized in the future for an infrastructure project such as the bridges. By the time the Frankfurt bridges are built, after several years of planning, infrastructure projects in Germany will generally produce fewer CO_2 emissions: on the one hand, through progress in research and development for all materials, and on the other hand, through the ever-advancing expansion and optimized use of renewable energies.

With the help of the Frankfurt bridges, Frankfurt has the opportunity to achieve its ambitious CO_2 reduction plans by 2050.

The respective effects of the 11 levers take effect at different times

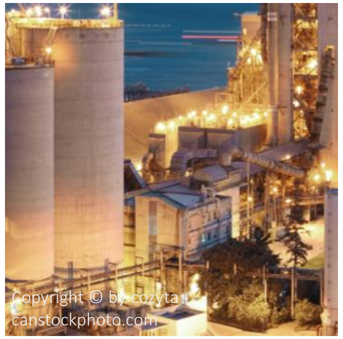


If all the stops are pulled out, around three quarters of the 1.5 million tons of CO_2 equivalent GHG emissions from the construction of the Frankfurt bridges can be saved or offset

This is the result of the rough initial assessment from today's perspective, which is based on the rough and partly abstract quantification of all conceivable savings options. The 11 levers at a glance:

CO_2 reduction through the use of regional natural stone and wood - can be implemented directly during construction

On some sections of Frankfurt's bridges, steel and concrete can be partially or even completely dispensed with. Where structural requirements allow, regionally available materials such as natural stone and wood can be used, resulting in significantly lower CO_2 emissions. If a mix of non-reinforced concrete materials is used in all suitable sections of the bridge, CO_2 emissions can be reduced by a further **55,000 tons.**



CO_2 reduction through the use of eco-concrete - directly realisable during construction

New formulations in the cement industry will be able to reduce CO_2 emissions from concrete worldwide in the future - provided they are tested under real conditions. This is precisely where the Frankfurt bridges come on the scene - as a showcase for innovations. The bridges therefore make more of a contribution to the global reduction of cement-related emissions than they are likely to make in themselves. For this reason, a saving of only **20,000 tons is** assumed here.

CO_2 reduction through the use of carbon reinforcement instead of steel reinforcement - can be implemented directly during

If the reinforcing steel in concrete is replaced by carbon, a large proportion of the CO_2 emissions generated by the reinforcement can be avoided. As soon as carbon reinforcement is no longer produced primarily with petroleum, but there are more sustainable input materials for it, it will be able to make a significant contribution to CO_2 reduction worldwide. So far, only partial substitution has been estimated for the Frankfurt bridges, which is why a saving of only **35,000 tons has been** calculated for this.

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CO_2 reduction through geothermal energy - effective in the medium term

Geothermal probes are integrated in advance into a large part of the piers of the Frankfurt bridges, so that they are geothermally active and supply clean energy for heating and cooling the buildings on the bridges. In this way, up to 15 GWh of thermal energy from the combustion of natural gas can be substituted annually. As the conversion to geothermal systems for Frankfurt's building stock will still take a long time, Frankfurt's bridges will still be able to provide a compensation service for other heating systems for at least 10 years, which is why a saving of around **30,000** tons of CO_2 seems plausible.

CO_2 reduction through clean drive energies - effective in the medium term

In times of the traffic turnaround, the Frankfurt bridges with their seven hydrogen filling stations and countless charging stations will be an additional stimulus in terms of clean drive technologies. This will lead to an accelerated shift from the combustion engine to hydrogen and electric cars. Calculated over two years, the Frankfurt bridges can be credited with a potential saving of around **240,000** tons of CO_2

CO_2 reduction through autonomous driving - effective in the long term

The autonomously driving traffic on the Frankfurt bridges will lead to a significant reduction in private vehicles, so that fewer cars will have to be manufactured in the long term. Due to the uncertainty about the extent of the effect, the CO_2 saving was described with a very conservative value of **50,000** tons.

CO_2 reduction through potential bridge arch houses - effective in the long term

Building areas can be created under the bridge arches (in the distant future). For these buildings, structural components made of steel and concrete are not required, as ceilings and piers already exist. Therefore, **30,000 tons** can be deducted from the CO_2 footprint of the bridges.

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CO_2 reduction through hydrogen-based steel production - can be implemented directly during construction

The steel used for the Frankfurt bridges should ideally come from manufacturing processes in which hardly any CO_2 emissions are produced thanks to innovative hydrogen-based processes. It is true that steel produced in this way will be increasingly available in the next few years. In view of the expected supply bottlenecks for green steel, the CO_2 savings for the Frankfurt bridges have been limited to **265,000** tons as a precaution.

CO_2 reduction through carbon capture during cement production - can be implemented directly during construction

By using the oxygen obtained by electrolysis to capture the CO_2 during cement production, the climate impact for a part of the greenhouse gases produced can be prevented. This gives the concrete a better CO_2 balance. As the process is currently still in the trial phase, a conservative saving of **50,000** tons of CO_2 was assumed for the Frankfurt bridges.

CO_2 reduction through diverse use of the bridge corpus - effective in the medium term

The body of the bridge fulfils the function of foundation slabs for the buildings on the bridges. If the housing were built on a greenfield site, the concrete would have to be consumed there. Thus, around **60,000 tons of** CO_2 of the bridge corpus are to be credited to the buildings - and not to the Frankfurt bridges.

CO_2 reduction through photovoltaics - effective in the medium term

The urban energy revolution is taking place on Frankfurt's bridges. With the help of solar modules for photovoltaics and solar thermal energy alone, up to 135 GWh of electricity from fossil energy sources can be substituted annually. Against the background of Frankfurt's climate goals of becoming climate-neutral by 2050 and dispensing with the burning of hard coal and natural gas, the Frankfurt bridges are likely to continue to play a compensatory role in the area of energy supply for at least five years. A total CO_2 saving of **300,000** tons is therefore realistic.

Independent of the bridges: Due to technological progress until the start of construction of the Frankfurt bridges, further CO_2 savings are potentially to be expected, which, however, were not taken into account in the calculation here

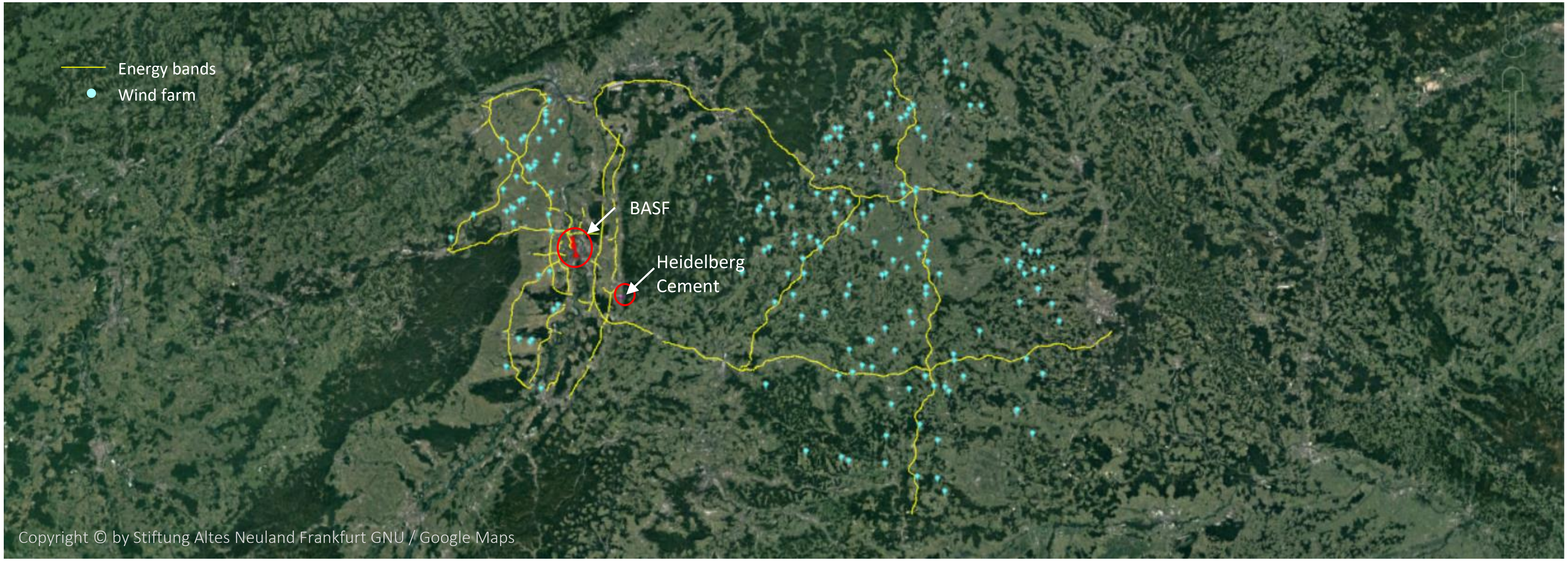
If one adds up the carefully estimated savings of all 11 levers, it is also clear: 395,000 tons of CO_2 remain - albeit at the 2022 level, with technologies from 2022. Research and developments for CO_2 reduction in construction are progressing rapidly.

By the time construction of Frankfurt's bridges begins in 2027, other technologies could have matured that could help the bridges become climate-neutral, perhaps even climate-positive.

This has not been taken into account in the CO2 savings levers: The levers only mention potentials that are related to the bridge concept.

Another potential independent of the bridge concept: CO_2 reduction in the production of concrete through more massive use of renewable energies

Infrastructure projects usually source their concrete from the region in order to keep the transport costs for the material masses as low as possible. If the cement is produced in the regionally based concrete plants with the help of surpluses from regionally generated renewable energy, "green cement" is produced: However, this requires power lines to be laid from solar and wind farms to the plants. Since this requires a considerable investment in line infrastructure, such a regional measure is only worthwhile if projects of the magnitude of the Frankfurt bridges or, for example, the Frankfurt long-distance rail tunnel are in the pipeline. And even then, power line routes are costly. Moreover, the electricity from wind and solar parks is usually sold for years even before the parks are built. The cement for the Frankfurt bridges should therefore be produced with the help of "energy belts: These conduct electricity generated photovoltaically along highways to industrial companies - for example, to the plants of HeidelbergCement.



The installation of energy ribbons on motorways and federal highways can help Frankfurt reduce its energy supply from fossil-fuelled power stations more quickly

Photovoltaic ribbons can be set up along federal roads and motorways, whose electricity can be fed directly to the respective consumers: These can be industrial plants, charging stations for e-cars or water filling stations etc. in the Rhine-Main area. Surplus electricity from the energy belts is stored in underground hydrogen tanks on the right and left of the roads.

As soon as the Frankfurt bridges concept is implemented, both the ideas realised and the additional bridge infrastructure created will lead to further CO_2 savings in Frankfurt

The sustainability of the bridge concept(s) should not only be considered in isolation, but also in its impact on the rest of the city:

If photovoltaics are installed on Frankfurt's bridges, for example, they must be aesthetically pleasing or invisible close to the city centre, as this acts like a showcase for other homeowners to encourage more photovoltaics to be installed in the established urban area. Or, if people first use autonomously driving vehicles on Frankfurt's bridges without hesitation, they will also find it much easier to get into autonomously driving vehicles on the road at some point. In this way, the innovative approaches on the bridges help to realize these innovations in the existing buildings next to the bridges.

In very concrete terms, the bridge's energy generation can help supply consumers in the city's stock: the surplus electricity on sunny days can be made available for electric cars to charge at the bridge's pillars; the geothermal energy, like its conduction system, can also be made usable for buildings to the right and left. This direct contribution of the bridges to CO_2 savings for Frankfurt can potentially be expanded even further.

Future vision for Frankfurt: the city becomes CO_2-neutral

A **ground-level geothermal system** not only supplies the bridges and residents' buildings (with activated building surfaces) with heating and cooling, but also serves as a conduction system for waste heat from computer centres and other heat sources from the Frankfurt waste heat register.

Photovoltaics are invisibly integrated everywhere on new buildings and urban areas, and intelligent control systems reduce electricity demand throughout the city.
It also reduces storage losses through intelligent peak load utilization and bidirectional electricity use with vehicles.

The Frankfurt Bridges pillar landscape, with its offer of thousands of **charging options** at the parking spaces next to the pillars, have led to a high penetration of electric cars. The 8 **hydrogen filling stations of** the bridges in all directions have also caused the number of hydrogen cars to grow. Vehicles with internal combustion engines are almost non-existent.

Autonomous driving has been introduced in the city. When vehicles arrive from outside the city, they connect to the central control system upon entering the urban area, and the driver behind the wheel can sit back and relax.

Green areas in the city, made possible by the irrigation system of the Frankfurt bridges, reduced the CO_2 content of the air by up to 200 tons per square kilometre p.a. Of the 250 km^2 urban area, it was possible to unseal and green 25 % of the traffic routes (50 km^2) in particular. A further 10 square kilometres have been added by greening facades and roofs.

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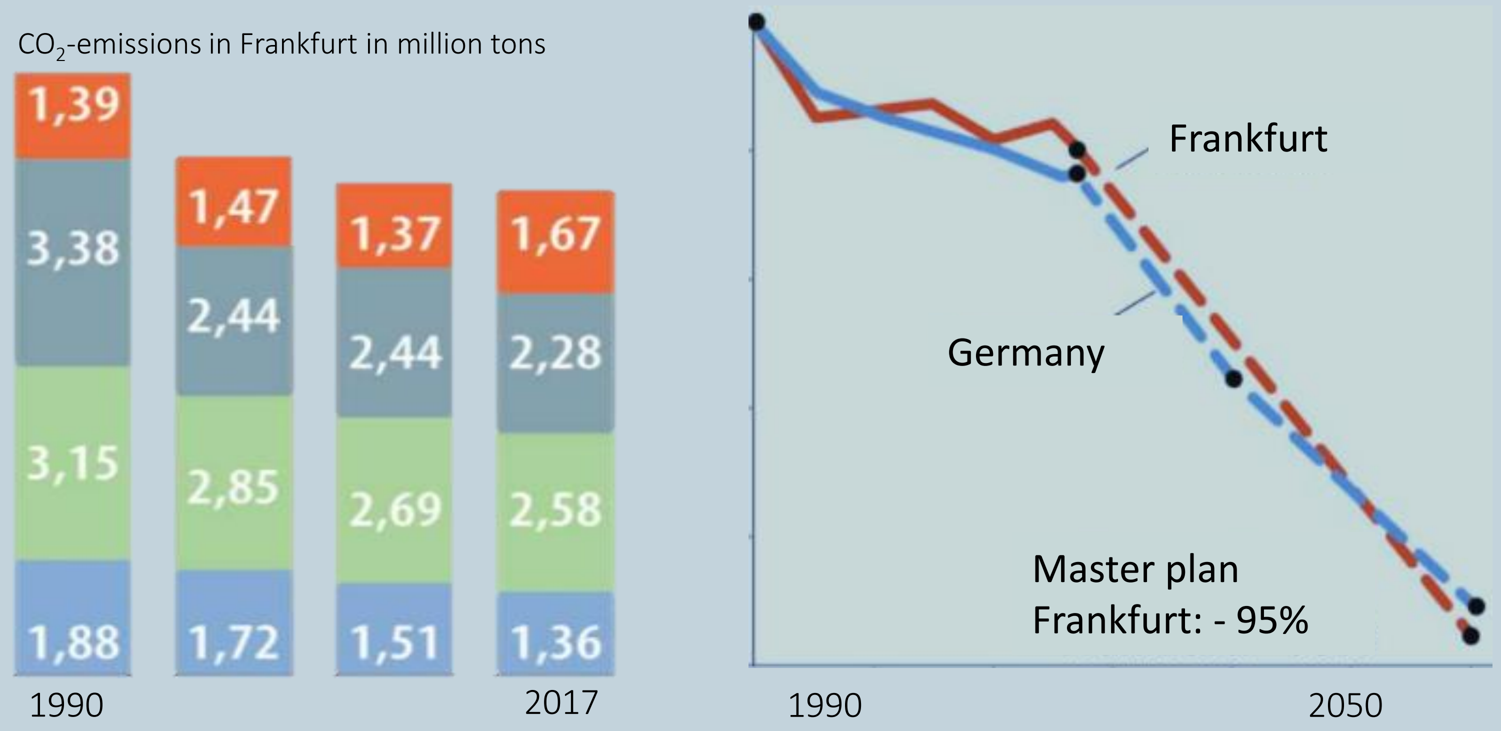
If the energy-saving concepts of Frankfurt's bridges gradually spread to the city, Frankfurt could achieve its CO_2 master plan target by 2050



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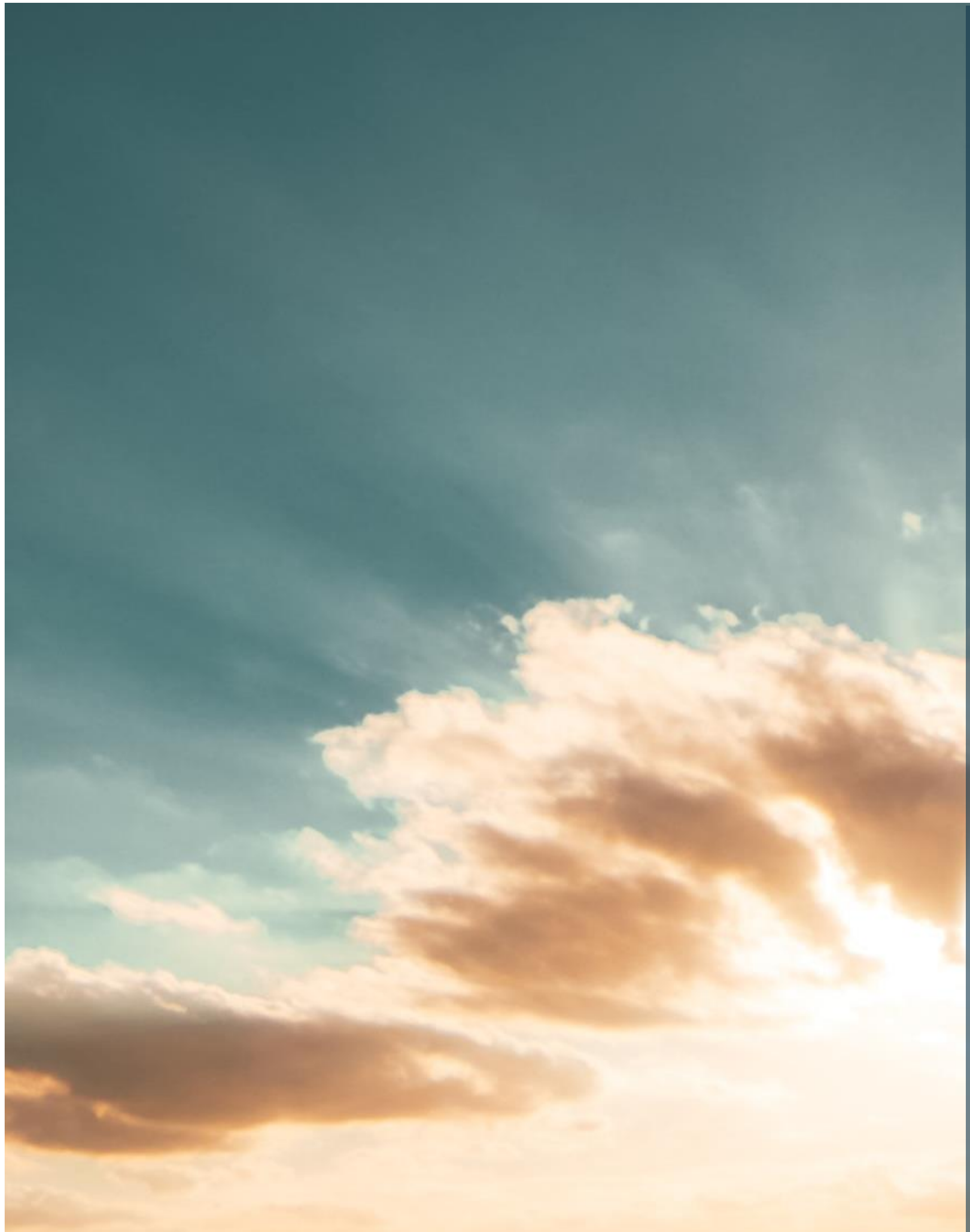

Conclusion: With the Frankfurt bridges, Frankfurt has a chance to achieve its goal of CO_2 neutrality by 2050

As with other major infrastructure projects, the construction of the Frankfurt bridges also releases large quantities of CO_2, mainly during the production of the concrete and steel required.

In order to keep the harmful effects on the global climate as low as possible, all available options (levers) are therefore being considered, through which the potentially emitted greenhouse gas of around 1.5 million tons of CO_2 can be reduced by around three quarters to 395,000 tons of CO_2.

The total savings of all CO_2 saving options for the Frankfurt bridges therefore amount to around 1.1 million tons of CO_2.

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The goal: to arm the city against drought and floods


The green metropolis of the future


Vitalization of the urban green

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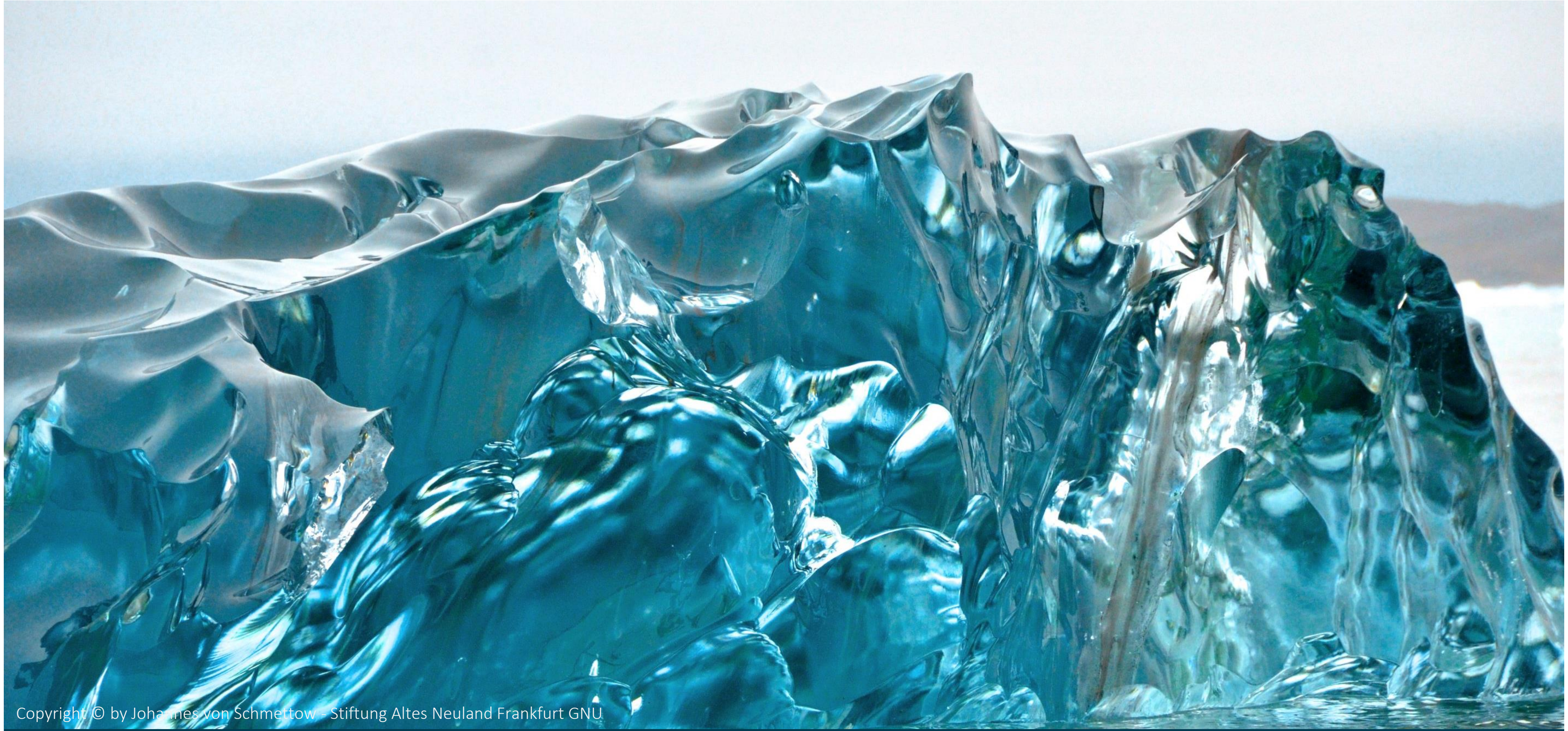


Urban Climate - Global Climate: Old Uncharted Territory Worldwide

In the city of the future, CO_2 emissions can be reduced: Smart urban planning enables the use of renewable energies for transport and utilities - and the use of alternative building materials as well as "green steel" and "eco-concrete" can significantly improve the CO_2 balance of construction projects worldwide.

Living and building in cities must be redefined - because this will be decisive for life on our planet

More than half of all people worldwide already live in cities rather than in the countryside. By 2050, the proportion of city dwellers is expected to rise to just under 70%.

How we live and build in cities will significantly shape climate change, but also social change on our planet. The concept of the Frankfurt Bridges is groundbreaking for the most important points that urban planning must take into account in the future in order to have cities that are as humane as they are sustainable. Hypermodern, gigantomaniac urban structures that destroy everything old and grown are NOT characteristics of the humane city of the future.

Rather, the Frankfurt bridges show how the most important trends of the future can be introduced integratively into existing conurbations. For ecological reasons alone, not everything old can be completely torn down and rebuilt. So we have to deal with what is there - and what is also very often lovable and worth preserving.

The Frankfurt Bridges show a quarter solution for all urban planning and living areas: from a new quarter in the middle of the old city area, which can rub off on the surrounding existing quarters and successively change them.

On a meta-level, the Frankfurt bridges implement a neighbourhood construction method that can be a catalyst and role model for urban planning of the future worldwide

What if... .

All cities have autonomous driving traffic

Invisibly generate photovoltaic electricity on all suitable urban surfaces

All new buildings to be equipped with ground-source geothermal energy

All new buildings receive thermally activatable surfaces

All supply systems intelligently controlled Save energy

All open spaces in the city to be irrigated and landscaped

All shops and catering establishments are connected to a low-packaging system

All things that are broken, can be repaired cheaply and promptly

How much CO_2 could be saved?

A first estimate: At least half of urban CO_2 emissions could be avoided - by the modern city of the future: Realized in the old stock and with more quality of life

Eco-concrete as a proven building material reduces CO_2 emissions during construction by 30% or more

Carbon reinforcement can reduce CO_2 emissions during construction by up to 30%.

Autonomously controlled traffic in the city
reduces energy consumption of vehicles by at least 50%
Reduces vehicle damage and wear and tear and therefore production by more than 70%.
enables greening of traffic areas

Integrated photovoltaics including control: invisible everywhere, reduces power generation through fossil combustion by 70% and storage losses through intelligent peak load use by 30%.

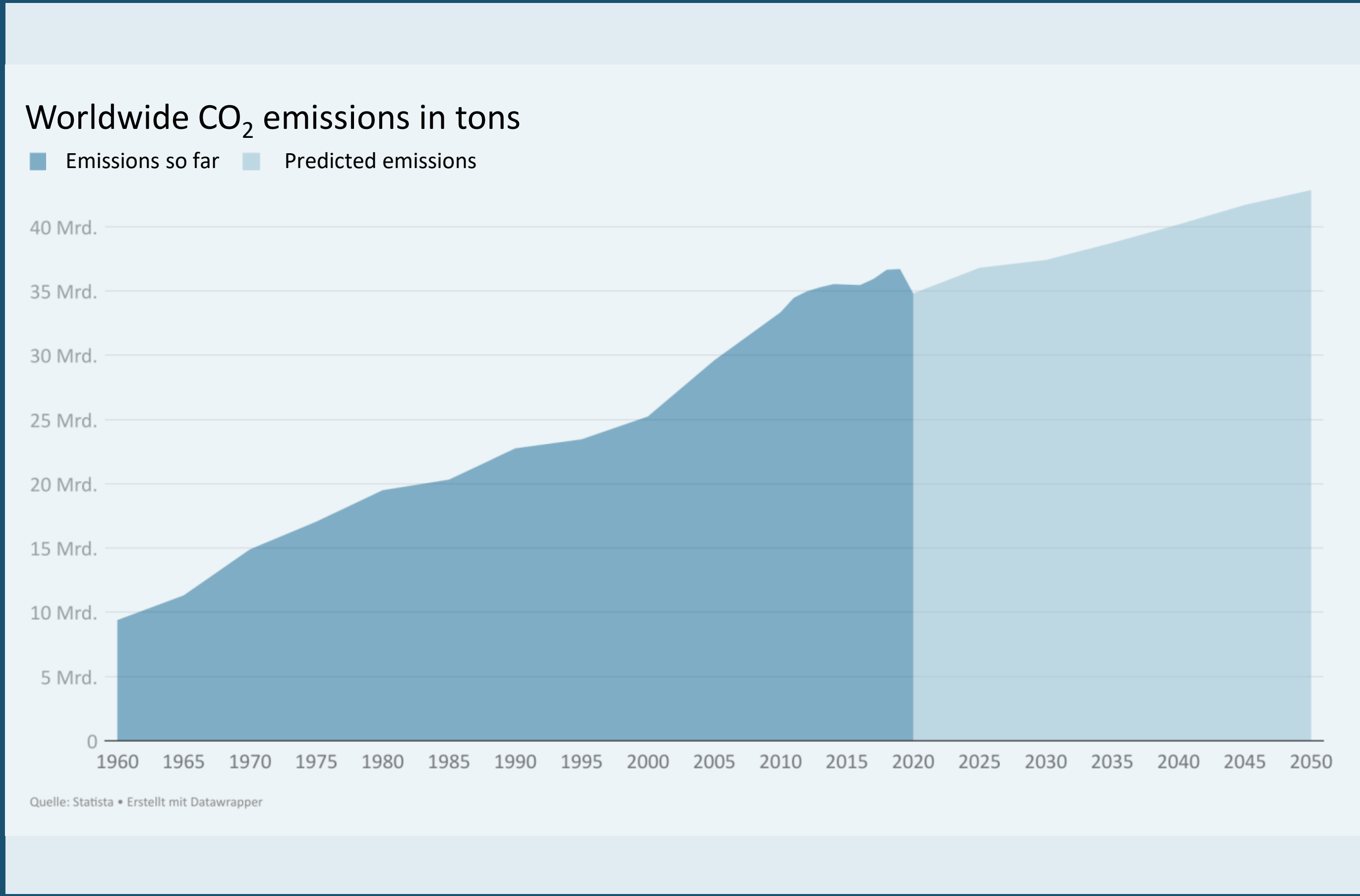
Ground-source geothermal energy in the city reduces heating and cooling by 50% through fossil combustion

Building with thermally activated surfaces reduces heating energy consumption by up to 40%.

Green areas in the city through irrigation systems reduce the CO_2 content of the air by up to 2 tons per hectare.

Turning away from the throwaway culture not only reduces microplastic from packaging waste by 80%, but also avoids 50% of CO2 emissions in the case of complexity-reduced plastic.

More than 35 billion tons of CO_2 are emitted worldwide every year: Stopping the increase alone is already a challenge



The Frankfurt bridges can make an immense contribution to this Herculean task as a showcase of potential and CO_2-saving innovations for major cities.

Research and development from all over Europe can be tested and developed live here.

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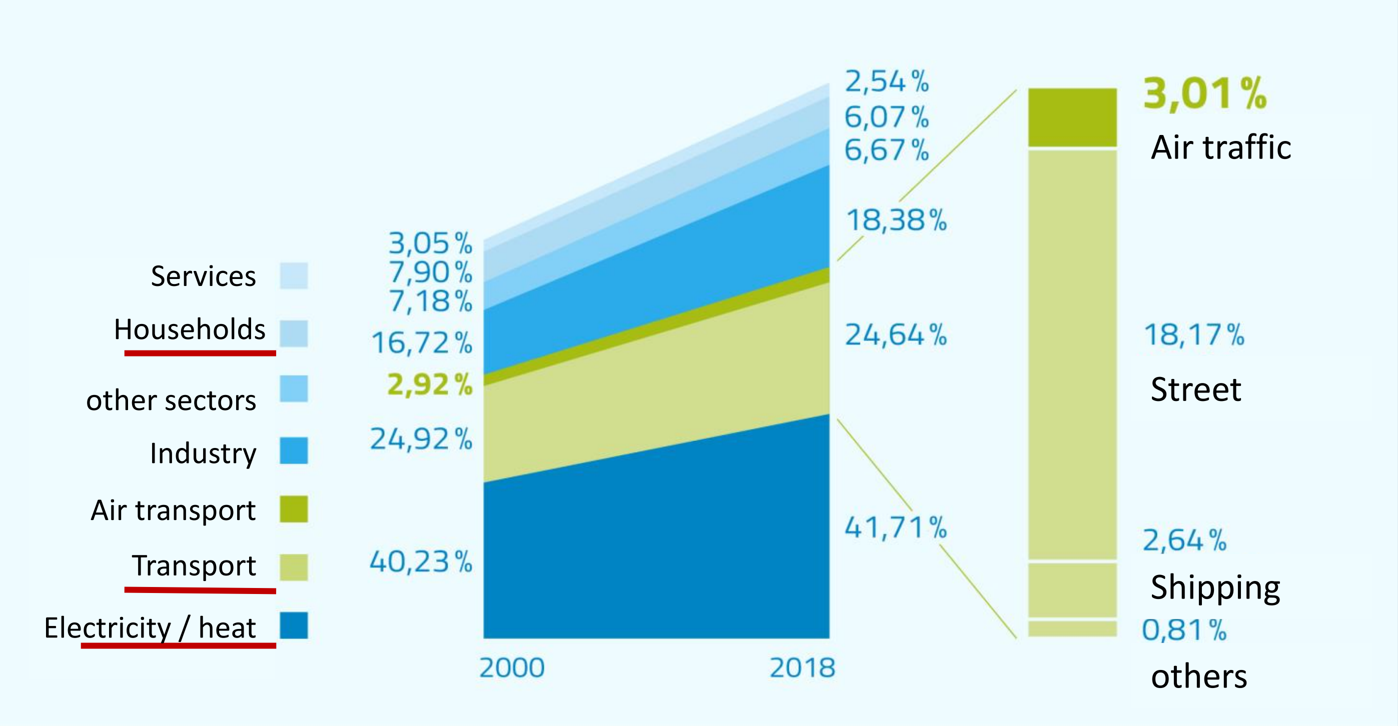
The concepts of the Frankfurt bridges address half of all CO_2 emission drivers

Transportation, heating, electricity and construction - these can be significantly optimized in cities. But the rest also needs to be addressed.



*Measured in terms of CO_2-emissions from the combustion of fossil fuels

CO_2 must be saved by all means - because once in the atmosphere, it cannot yet be bound again on a large scale

Carbon capturing is a hopeful approach to reducing CO_2 in the atmosphere. However, it is only a good approach if it is operated exclusively with renewable energy (geothermal energy), as is the case in Iceland.

However, the largest plant in the world to date only manages to suck 4,000 tons of carbon dioxide out of the air each year and press it into the ground - and requires 25 tons of water per tonne of CO_2. A (costly) drop in the ocean.

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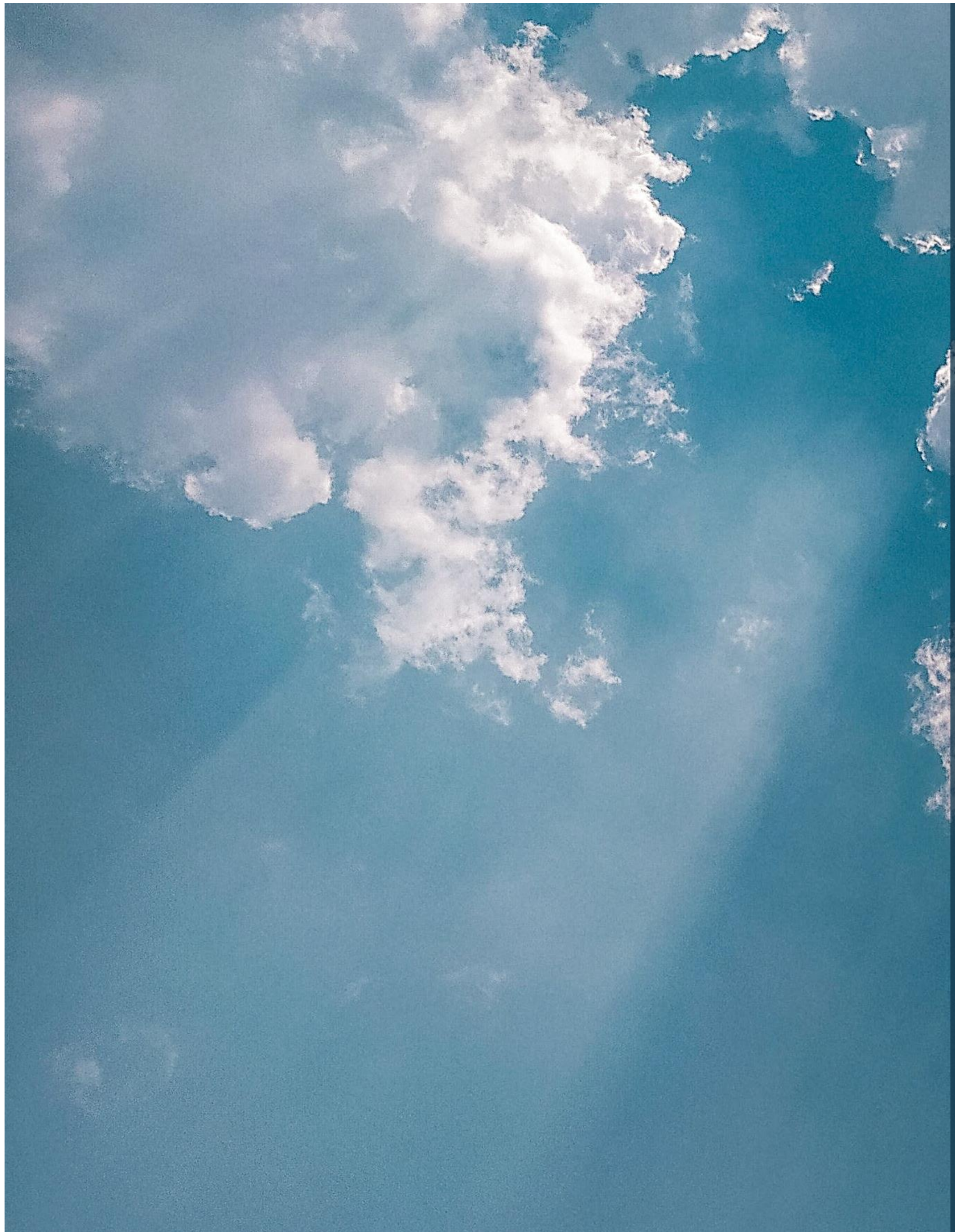

Conclusion: The Frankfurt bridges are an innovative signpost for reducing CO_2 emissions in cities and thus make an important contribution to achieving global climate targets

In the face of melting polar ice caps, drought and floods, it may not be enough - but without changing cities, it won't be possible to reduce the billions in emissions.

Cities will never become CO_2 sinks, no matter how much greening they do. But they can help to stop emissions from growing.

The international joint efforts of all countries to reduce CO_2 must rely even more strongly than before on innovations in order to achieve the CO_2 target by 2050.

And innovations can only experience a roll-out once they have a platform on which they have proven themselves - for example, the Frankfurt bridges.

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