ETH Zurich Department of Architecture
ARCHITECTURE OF TERRITORY
Chair of Architecture
and Territorial Planning
Professor Milica Topalović

Power to the People
Fall 2022

Atlas

Grid and Networks

Timon Droll, Charis Gersl, and Flavio Thommen

The electrical grid is an interconnected network for electricity delivery from producers to consumers. Without the grid, energy could only be used where it is generated. Notwithstanding its importance, the grid has remained an abstract, hidden element of the planet's energy supply, often omitted in debates on energy transition. To shed light onto the electrical grid, the following questions will be answered in the following: What infrastructure does the grid comprise? How does the energy transmission work? And how does it impact its surroundings?



Hidden Networks

They are over, under, between and next to us. They surround us. They connect us. They make our cities function and the life that we know possible. The grids of communication are omnipresent in our lives, but physically hidden at the same time.



HYDRANT
Water supply of a city



ELECTRICITY BOX
Connecting city and country



POSTBOX
Global distribution



ELECTRICITY NETWORK
IN CONTINENTAL EUROPE
Source: ENTSO-E
[https://www.entsoe.eu/data/map/]

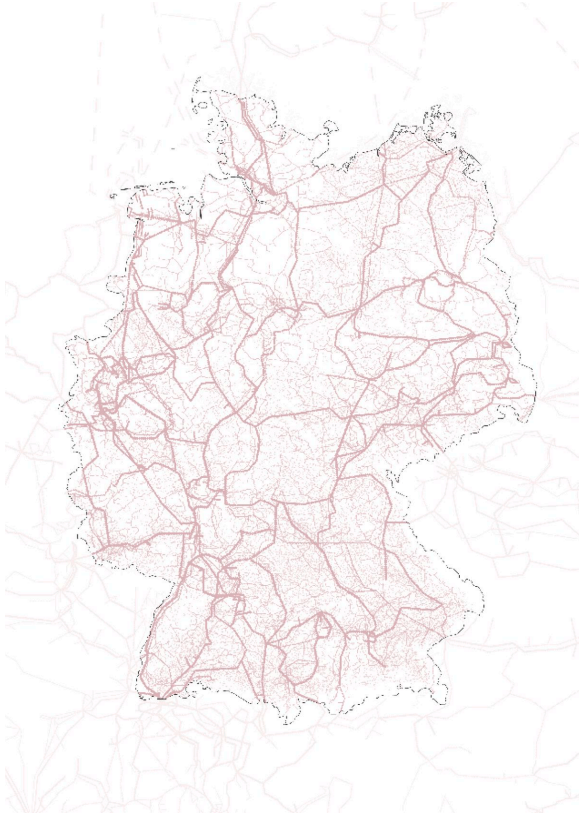


ELECTRICITY NETWORK AND
METROPOLITAN REGIONS
Source: ENTSO-E
[https://www.entsoe.eu/data/map/]

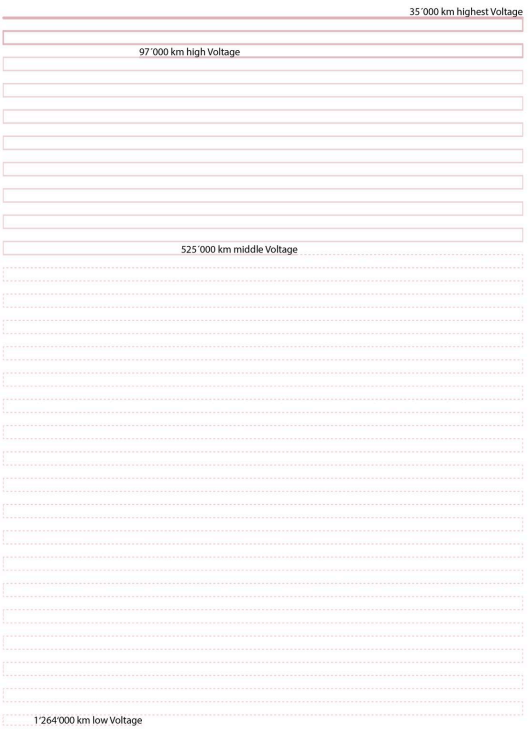


THE PROJECT FOR A
TRANSCONTINENTAL SUPER GRID
Source: ENTSO-E
[https://www.entsoe.eu/data/map/]

AC high voltage lines (alternating current) do not transport electricity from producer to consumer over very long distances, because of the energy loss. However, there are plans for a super grid with DC high voltage transmission lines (direct current) to connect alternative energy sources from north to south.With such a grid, the local potential of renewable energy could be fully utilised and transported to regions where the energy is needed.

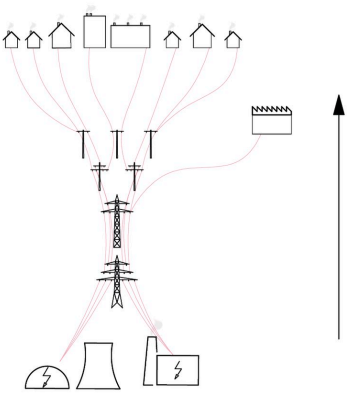


POWER LINES IN GERMANY
Source: ENTSO-E
[https://www.entsoe.eu/data/map/]

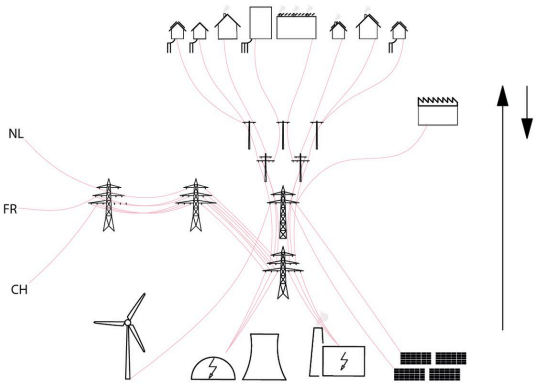


TOTAL LENGTH OF POWER LINES IN GERMANY

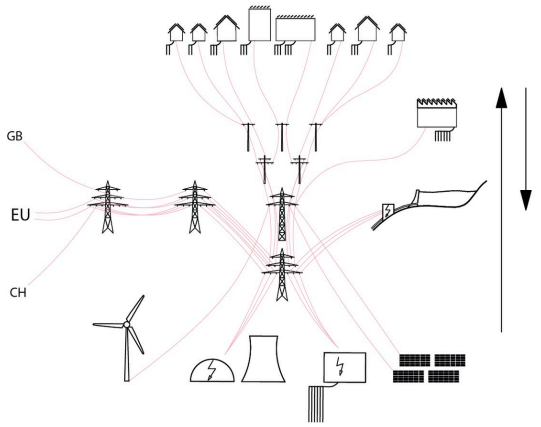
The total length of all power lines in Germany (high voltage, medium voltage, low voltage) is 1,921,000 kilometres. This equals to 48 times the circumference of the earth. Only 35,000 kilometre are the high voltage lines (1,8 %), which are constructed over ground. Low-voltage lines make up the largest part with 1,260,000 kilometres (66 %). They lie underground and are therefore invisible for our yes.



The electrification began in Germany around 1880. The power production was based on non-renewable energy sources, and the energy was transported as alternating (AC) and direct current (DC). Over time, the AC became the predominant type of electrical power because it allowed for the transport of electricity over long distances without huge losses.



Over time, the system developed: With a more diverse range and number of producers and new connection lines, the grid became more complex. Thanks to the densification of the grid, regions and countries could help each other out during shortages and blackouts could be reduced.



Only since 2009, the European grids are connected and managed in close collaboration. Power imports and exports of most countries roughly balance each other out. With more and more renewables entering the grid a power producing the entities, the grid is confronted with new challenges regarding its stability.

They are over, under, between and next to us. They surround us. They connect us. They make our cities function and the life that we know possible. The grids of communication are omnipresent in our lives, but physically hidden at the same time.



HYDRANT
Water supply of a city



ELECTRICITY BOX
Connecting city and country



POSTBOX
Global distribution



ELECTRICITY NETWORK
IN CONTINENTAL EUROPE
Source: ENTSO-E
[https://www.entsoe.eu/data/map/]

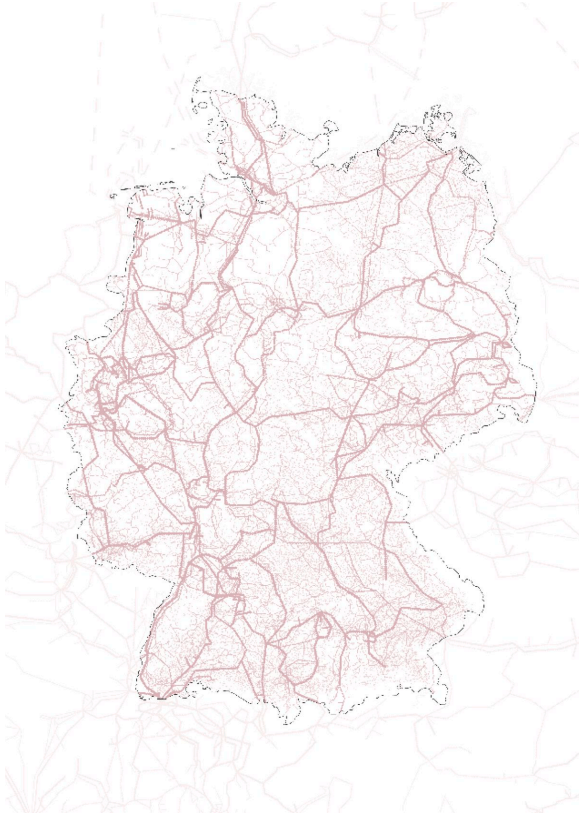


ELECTRICITY NETWORK AND
METROPOLITAN REGIONS
Source: ENTSO-E
[https://www.entsoe.eu/data/map/]

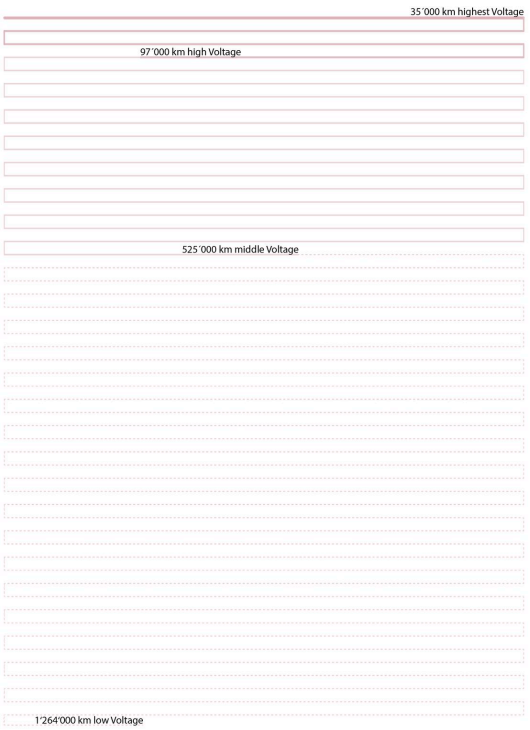


THE PROJECT FOR A
TRANSCONTINENTAL SUPER GRID
Source: ENTSO-E
[https://www.entsoe.eu/data/map/]

AC high voltage lines (alternating current) do not transport electricity from producer to consumer over very long distances, because of the energy loss. However, there are plans for a super grid with DC high voltage transmission lines (direct current) to connect alternative energy sources from north to south.With such a grid, the local potential of renewable energy could be fully utilised and transported to regions where the energy is needed.

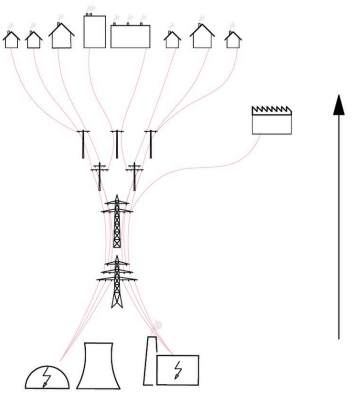


POWER LINES IN GERMANY
Source: ENTSO-E
[https://www.entsoe.eu/data/map/]

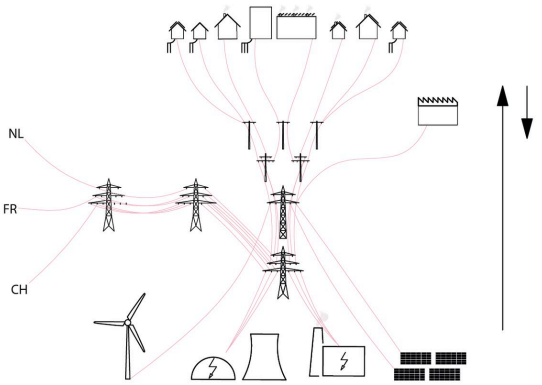


TOTAL LENGTH OF POWER LINES IN GERMANY

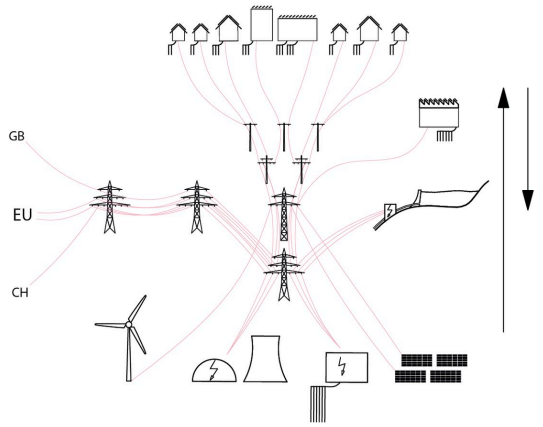
The total length of all power lines in Germany (high voltage, medium voltage, low voltage) is 1,921,000 kilometres. This equals to 48 times the circumference of the earth. Only 35,000 kilometre are the high voltage lines (1,8 %), which are constructed over ground. Low-voltage lines make up the largest part with 1,260,000 kilometres (66 %). They lie underground and are therefore invisible for our yes.



The electrification began in Germany around 1880. The power production was based on non-renewable energy sources, and the energy was transported as alternating (AC) and direct current (DC). Over time, the AC became the predominant type of electrical power because it allowed for the transport of electricity over long distances without huge losses.



Over time, the system developed: With a more diverse range and number of producers and new connection lines, the grid became more complex. Thanks to the densification of the grid, regions and countries could help each other out during shortages and blackouts could be reduced.



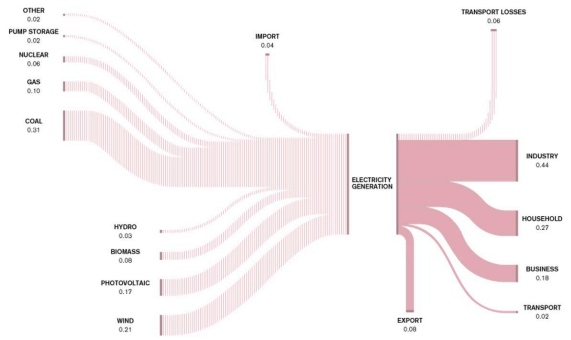
Only since 2009, the European grids are connected and managed in close collaboration. Power imports and exports of most countries roughly balance each other out. With more and more renewables entering the grid a power producing the entities, the grid is confronted with new challenges regarding its stability.

Flow of Electricity

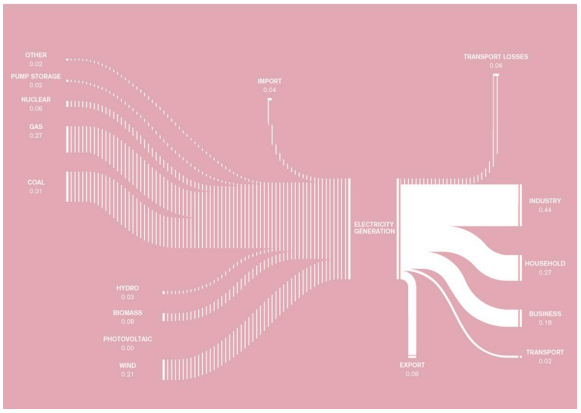


IMPORT AND EXPORT OF ELECTRICITY IN
GERMANY IN THE FIRST QUARTER OF 2022
Source: Stromdaten
[https://www.stromdaten.info/ANALYSE/importexport/index.php]

In the first quarter of the 2022, Germany supplied large amounts of electricity to foreign countries, compared to the amount of imported electricity. A major reason for the large export volumes was the growing amount of wind and solar power in the country. Most of the electricity, produced in Germany, flowed to Austria and Switzerland, while small volumes of imports came from Denmark and Sweden, as well as from Norway. In the entire quarter, there were only seven days on which Germany purchased more electricity from abroad than it exported. However, these short-term imports did not mean that all domestic capacity was exhausted. Cross-border electricity deliveries follow primarily market laws rather than technical necessities. In cross-border trade, electricity always flows from the cheaper to the more expensive country.



Electricity Generation during the Day
Source: DESTATIS
[https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/09/PD22_374_43312.html;jsessionid=DB9653E7CD840E1751D106D8750CFBDF.live732]



Electricity Generation during the Night
Source: Destatis
[https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/09/PD22_374_43312.html;jsessionid=DB9653E7CD840E1751D106D8750CFBDF.live732]

For decades, Russian coal, oil and gas have contributed significantly to Germany's energy mix. With the proclamation of the *Energiewende* and in the face of the 2022 energy crisis due to the Russian-Ukrainian war, the state has advanced the expansion of renewable energies.

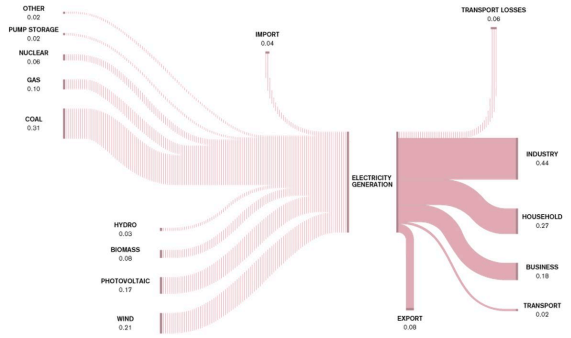
Today, around half of the power produced in Germany comes from renewable sources like sun or wind. At the same time, the demand and importance of coal-fired power grew, due to the stop of gas delivery from Russia. Therefore, coal still marks the main energy source today with around a third of the total amount of electricity. In contrast, alternative sources like biomass, nuclear or hydropower contribute little to the energy mix.

What kind of energy source feeds electricity to the grid is highly dependent on the weather, among other things: sun and wind do not always generate the energy when it is needed. This can mean that not enough electricity is produced when it is dark or there is no wind. In such cases, the missing amount of electricity must be compensated with other energy sources.

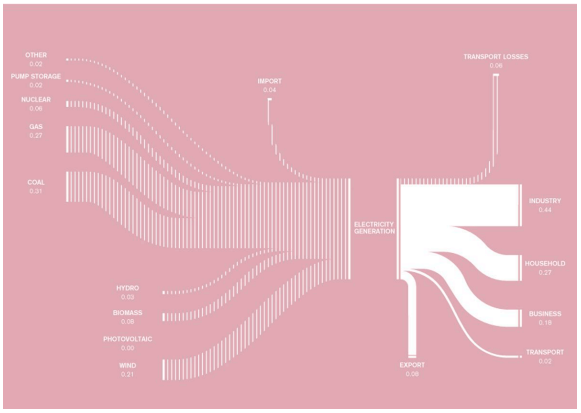


IMPORT AND EXPORT OF ELECTRICITY IN
GERMANY IN THE FIRST QUARTER OF 2022
Source: Stromdaten
[https://www.stromdaten.info/ANALYSE/importexport/index.php]

In the first quarter of the 2022, Germany supplied large amounts of electricity to foreign countries, compared to the amount of imported electricity. A major reason for the large export volumes was the growing amount of wind and solar power in the country. Most of the electricity, produced in Germany, flowed to Austria and Switzerland, while small volumes of imports came from Denmark and Sweden, as well as from Norway. In the entire quarter, there were only seven days on which Germany purchased more electricity from abroad than it exported. However, these short-term imports did not mean that all domestic capacity was exhausted. Cross-border electricity deliveries follow primarily market laws rather than technical necessities. In cross-border trade, electricity always flows from the cheaper to the more expensive country.



Electricity Generation during the Day
Source: DESTATIS
[https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/09/PD22_374_43312.html;jsessionid=DB9653E7CD840E1751D106D8750CFBDF.live732]



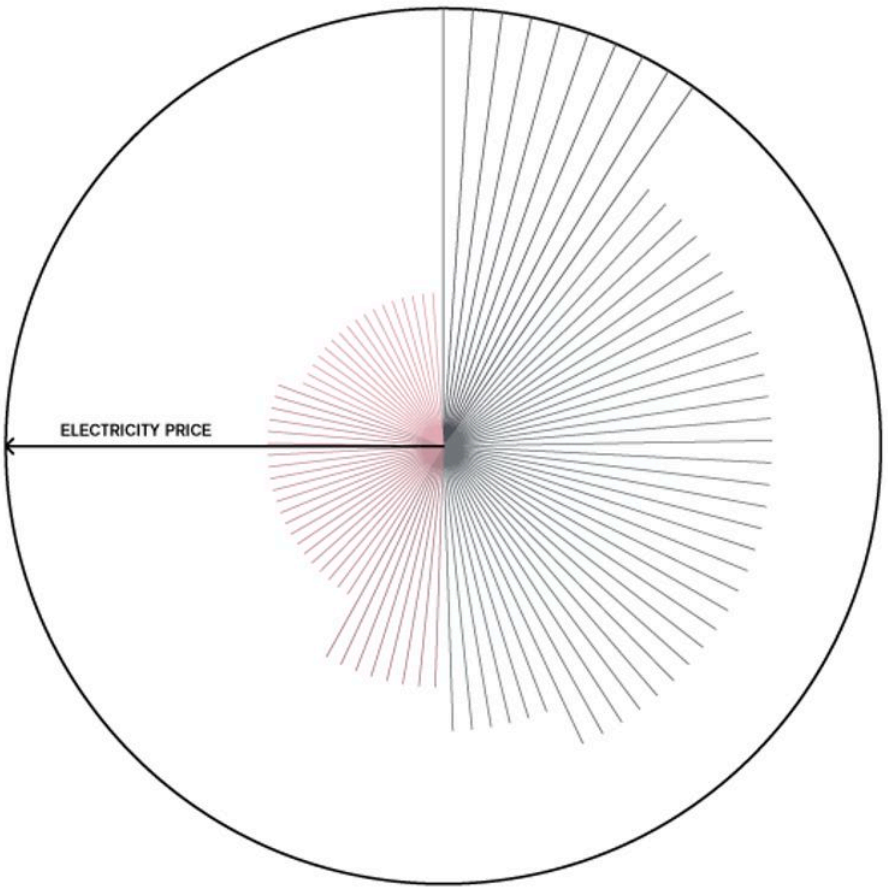
Electricity Generation during the Night
Source: Destatis
[https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/09/PD22_374_43312.html;jsessionid=DB9653E7CD840E1751D106D8750CFBDF.live732]

For decades, Russian coal, oil and gas have contributed significantly to Germany's energy mix. With the proclamation of the *Energiewende* and in the face of the 2022 energy crisis due to the Russian-Ukrainian war, the state has advanced the expansion of renewable energies.

Today, around half of the power produced in Germany comes from renewable sources like sun or wind. At the same time, the demand and importance of coal-fired power grew, due to the stop of gas delivery from Russia. Therefore, coal still marks the main energy source today with around a third of the total amount of electricity. In contrast, alternative sources like biomass, nuclear or hydropower contribute little to the energy mix.

What kind of energy source feeds electricity to the grid is highly dependent on the weather, among other things: sun and wind do not always generate the energy when it is needed. This can mean that not enough electricity is produced when it is dark or there is no wind. In such cases, the missing amount of electricity must be compensated with other energy sources.

Casino on the Electricity Market

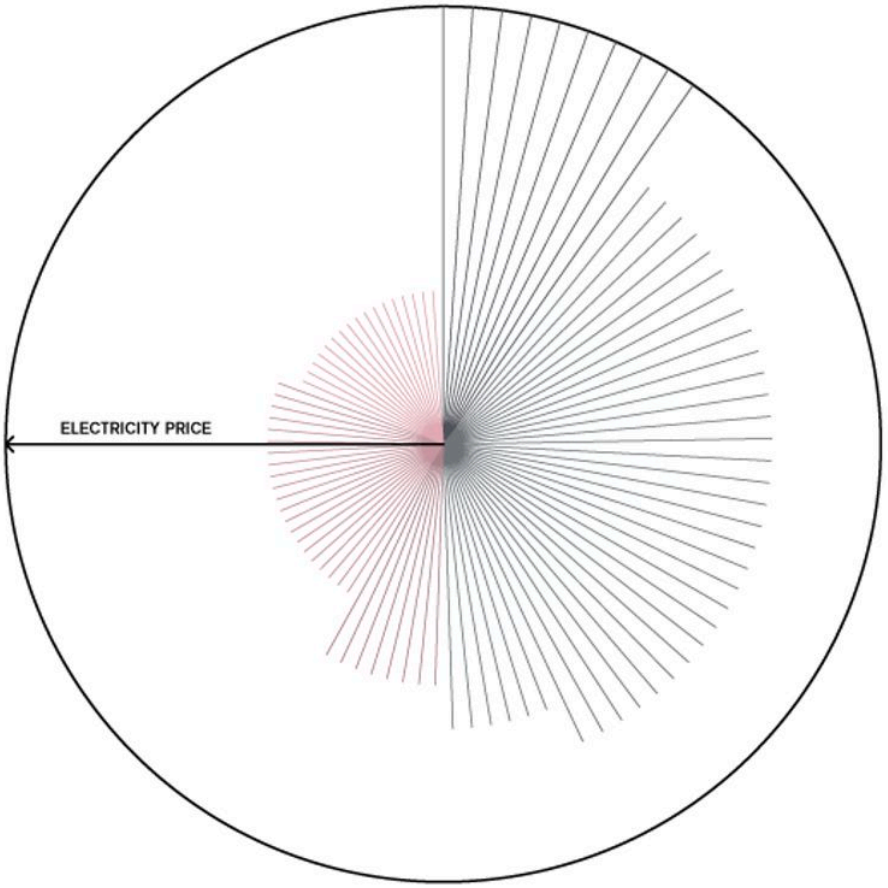


The graphic shows the different energy sources, which are needed to meet the current demand for electricity in Germany. On the right side there are the conventional energies like coal, gas and nuclear. The left side represents the renewable energy sources like sun, wind and biomass. The number of lines represents the importance of each energy source measured by the overall demand. The length of each line represents the level of the market price. In 2022, gas was the most expensive form of energy followed by coal.

Source: DESTATIS [https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/09/PD22_374_43312.html;jsessionid=DB9653E7CD840E1751D106D8750CFBDF.live732]

- Gas
- Coal
- Nuclear
- Biomass
- Wind
- Solar

The electricity pricing is based on a uniform principle throughout Europe. The power plants that can offer the best price are always the first to be selected. Wind and solar are among the cheapest electricity suppliers. The uniform regulation states that the most expensive power plant determines the price of electricity. In the case of Germany, gas determines the price. This means that all other less expensive suppliers sell the energy at the same price like gas. While the gas plant operator covers only the production costs, the other suppliers make profit.

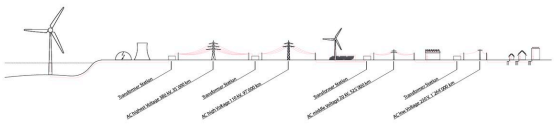


The graphic shows the different energy sources, which are needed to meet the current demand for electricity in Germany. On the right side there are the conventional energies like coal, gas and nuclear. The left side represents the renewable energy sources like sun, wind and biomass. The number of lines represents the importance of each energy source measured by the overall demand. The length of each line represents the level of the market price. In 2022, gas was the most expensive form of energy followed by coal.
Source: DESTATIS
[https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/09/PD22_374_43312.html;jsessionid=DB9653E7CD840E1751D106D8750CFBDF.live732]

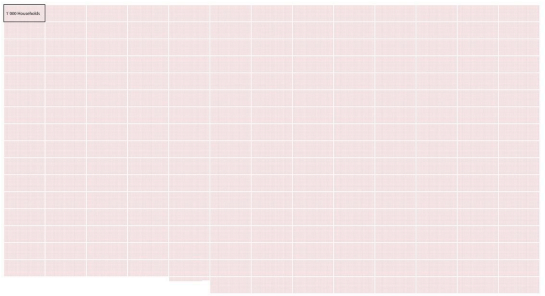
Gas
Coal
Nuclear
Biomass
Wind
Solar

The electricity pricing is based on a uniform principle throughout Europe. The power plants that can offer the best price are always the first to be selected. Wind and solar are among the cheapest electricity suppliers. The uniform regulation states that the most expensive power plant determines the price of electricity. In the case of Germany, gas determines the price. This means that all other less expensive suppliers sell the energy at the same price like gas. While the gas plant operator covers only the production costs, the other suppliers make profit.

From Producer to Consumer



DIFFERENT LEVELS OF THE GRID

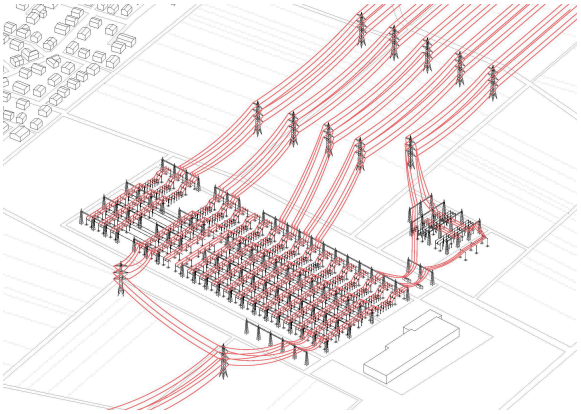


217,931 HOUSEHOLDS

Although electricity is not visible, it is constantly present and the foundation of modern life. Without electricity, no trains run, refrigerators do not work, and cashless bank transactions can not be completed.

In order to bring electricity from the renewable energy sources to the consumer quickly and with little losses, a well-developed electricity grid is important. Today, electricity is usually not used where it is generated. In order for the electrical energy to reach the consumers, a multi-level electricity grid with seven different levels is needed. Between the four networks of extra-high, high, medium and low voltage there are three transformer levels, where the extra-high voltage is gradually converted into low voltage.

The electricity grid consists of a transmission grid and a distribution grid. On the way from the power plant to the household the voltage is gradually reduced to 230 volt. At the beginning is the power source. From the power sources the electricity is fed into the extra-high voltage grid (380 kV). In this way, large amounts of electricity can be transmitted over long distances. They bring the electricity to the region of the consumers where it is reduced to a lower voltage. From the transmission grid the electricity is transferred to the high-voltage grid (36-150 kV). Here, it is taken over by industrial plants and local energy suppliers. For regional use the voltage is reduced a second time and fed into the medium-voltage (1-36 kV)grid. From this grid the electricity is distributed to city districts, villages and small and medium-sized industrial plants. Finally, the voltage is transformed to low voltage (>1 kV). The electricity then reaches the socket via the local power grid.



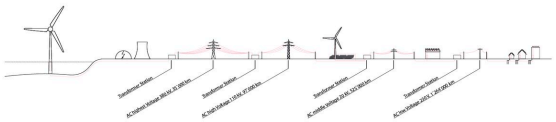
ELECTRICAL SUBSTATION OBERZIER



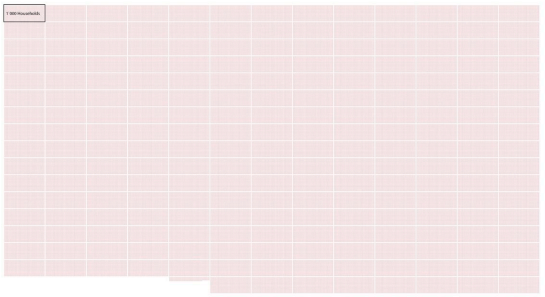
OPERATION BUILDING OF
ELECTRICAL SUBSTATION OBERZIER



DIFFERENT TECHNICAL ELEMENTS OF
ELECTRICAL SUBSTATION OBERZIER



DIFFERENT LEVELS OF THE GRID

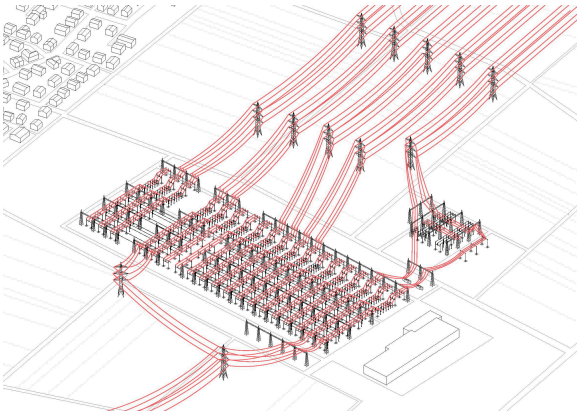


217,931 HOUSEHOLDS

Although electricity is not visible, it is constantly present and the foundation of modern life. Without electricity, no trains run, refrigerators do not work, and cashless bank transactions can not be completed.

In order to bring electricity from the renewable energy sources to the consumer quickly and with little losses, a well-developed electricity grid is important. Today, electricity is usually not used where it is generated. In order for the electrical energy to reach the consumers, a multi-level electricity grid with seven different levels is needed. Between the four networks of extra-high, high, medium and low voltage there are three transformer levels, where the extra-high voltage is gradually converted into low voltage.

The electricity grid consists of a transmission grid and a distribution grid. On the way from the power plant to the household the voltage is gradually reduced to 230 volt. At the beginning is the power source. From the power sources the electricity is fed into the extra-high voltage grid (380 kV). In this way, large amounts of electricity can be transmitted over long distances. They bring the electricity to the region of the consumers where it is reduced to a lower voltage. From the transmission grid the electricity is transferred to the high-voltage grid (36-150 kV). Here, it is taken over by industrial plants and local energy suppliers. For regional use the voltage is reduced a second time and fed into the medium-voltage (1-36 kV)grid. From this grid the electricity is distributed to city districts, villages and small and medium-sized industrial plants. Finally, the voltage is transformed to low voltage (>1 kV). The electricity then reaches the socket via the local power grid.



ELECTRICAL SUBSTATION OBERZIER



OPERATION BUILDING OF
ELECTRICAL SUBSTATION OBERZIER



DIFFERENT TECHNICAL ELEMENTS OF
ELECTRICAL SUBSTATION OBERZIER

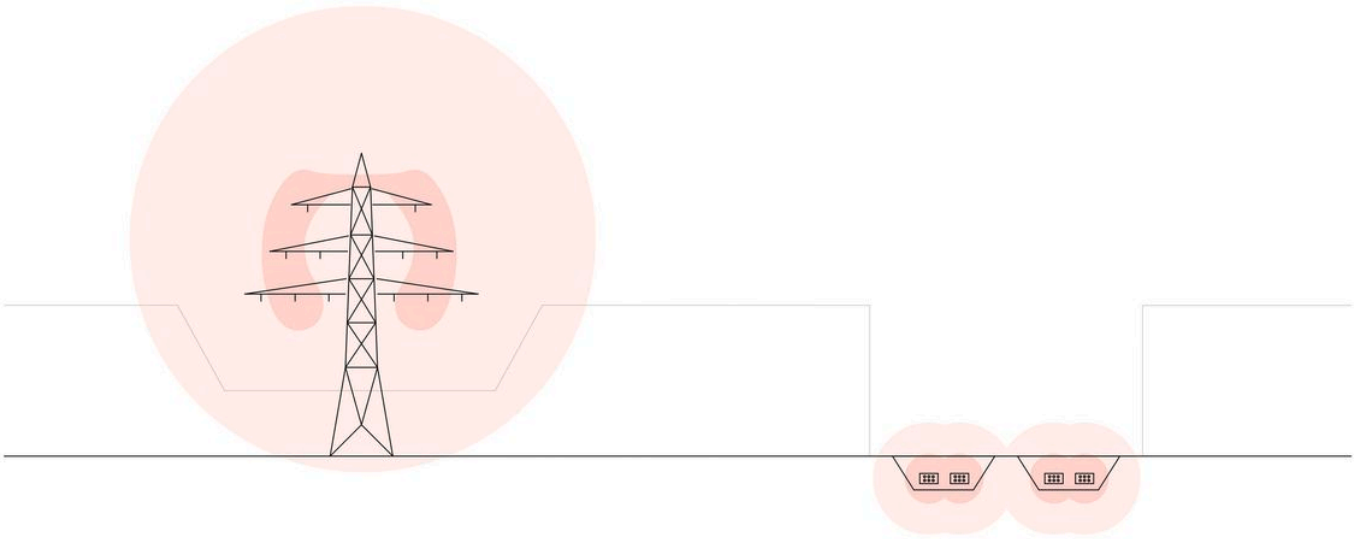
The Electrical Grid and Its Impacts

Some people consider electricity infrastructures as ugly or dangerous for the human health. Even though there are no studies proofing that these concerns are justified, surveys from the Bundesamt für Strahlenschutz (BfS) in Germany show, that many people are afraid of being too close to the infrastructures of the electrical grid.



Scusi Brancusi, Markus Müller, Basel (2009)

There are a lot of misconceptions and rumours about the impact of electricity networks on their surroundings. In Basel, for example, the artist Markus Müller put up a sculpture, right next to an office building, that looked like an antenna. Some people who worked there, or that were often in that area, started to complain about the lack of mobile phone reception and headaches, even though the antenna was not functional.



OVERHEAD LINES AND EARTH CABLES WITH ELECTROMAGNETIC FIELDS

- Treeline
- 100 Microtesla (people should not stay here for long)
- 1 Microtesla (no sensitive places like schools or playgrounds allowed)

Today, earth cables are becoming more common, because they are not as visible as overhead lines. They are often used near or in cities where there is not a lot of space or where it is more likely that people could reject the construction of new visible power lines. In addition, they have less outages and no noise emissions because they are protected in the ground. But if there is an outage it takes more time and money to repair it. That is s why overhead lines are used more often in the countryside because they are cheaper, can be repaired faster and have a longer life expectancy. Also, their energy transmission loss is smaller because they do not get as warm as the cables in the ground.



IMPACT ON NATURE

Transmission lines have a big impact on nature. They cut through the landscape and habitats, because the cables must never touch anything that is connected to the ground. Otherwise, there will be electrical flashovers which can lead to electrical shocks or fire. Also, noise and light emissions during the construction and the operation impact the nature.
Source: SOLAREIS [https://solareis.anl.gov/images/photos/transmissionROW.jpg]



IMPACT ON THE GROUND

Transmission lines have a big impact on the ground. The earth cables create indirectly cuts through the landscape because you can not build anything on top of them. The trees need to be at a certain distance, so that their roots do not damage the cables. Because of the heat that the earth cables create, there are speculations that the ground dries out and that the biodiversity decreases in the soil surrounding it.
Source: mbquadrat [https://mbquadrat.max-boegl.de/wp-content/uploads/2020/10/erdverkabelung-6.jpg]



IMPACT ON THE ECONOMY

Overhead lines take on so much space, that the land use underneath them is limited to agriculture. But even there, the use is restricted. Because of the poles it is more effort and less profit for the farmers than with normal fields. So, not only the land value under power lines decreases but also the land value surrounding them.



IMPACT ON THE PEOPLE

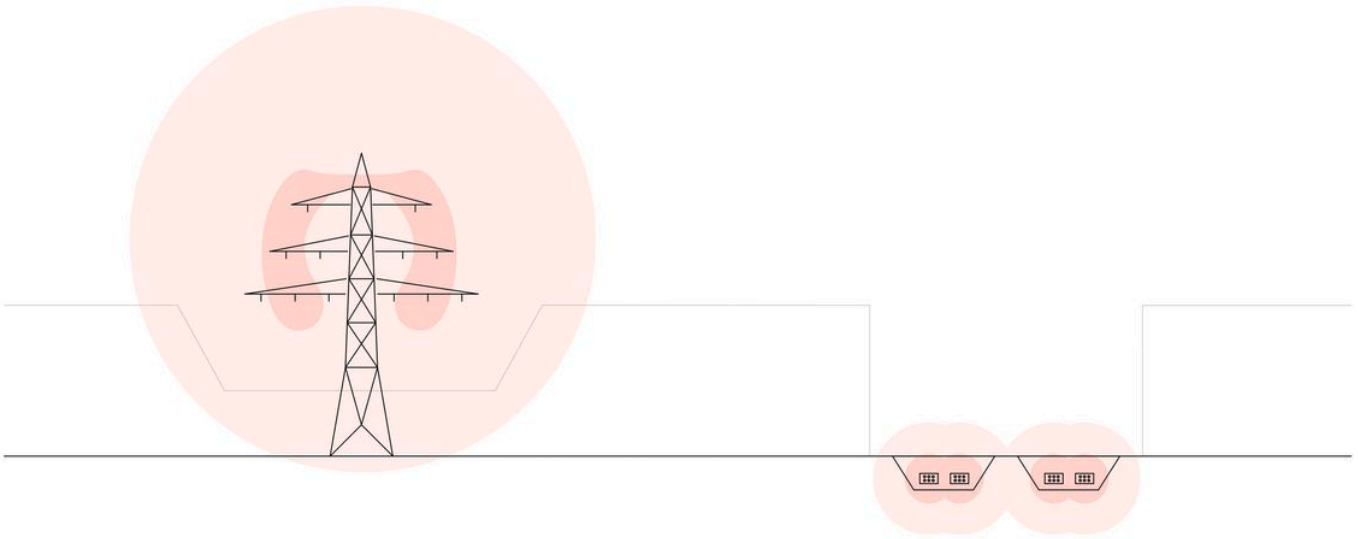
Overhead lines are visible from far away and change their surroundings. The opinions of people vary but many do not want them close to their property. A piece of land can thereby lose value if an overhead lines is built near it or on it.
Source: Baubiologie Magazin [https://baubiologie-magazin.de/site/wp-content/uploads/abstand-zwischen-haus-und-hochspannung-1.jpg]

Some people consider electricity infrastructures as ugly or dangerous for the human health. Even though there are no studies proofing that these concerns are justified, surveys from the Bundesamt für Strahlenschutz (BfS) in Germany show, that many people are afraid of being too close to the infrastructures of the electrical grid.



Scusi Brancusi, Markus Müller, Basel (2009)

There are a lot of misconceptions and rumours about the impact of electricity networks on their surroundings. In Basel, for example, the artist Markus Müller put up a sculpture, right next to an office building, that looked like an antenna. Some people who worked there, or that were often in that area, started to complain about the lack of mobile phone reception and headaches, even though the antenna was not functional.



OVERHEAD LINES AND EARTH CABLES WITH ELECTROMAGNETIC FIELDS

- Treeline
- 100 Microtesla (people should not stay here for long)
- 1 Microtesla (no sensitive places like schools or playgrounds allowed)

Today, earth cables are becoming more common, because they are not as visible as overhead lines. They are often used near or in cities where there is not a lot of space or where it is more likely that people could reject the construction of new visible power lines. In addition, they have less outages and no noise emissions because they are protected in the ground. But if there is an outage it takes more time and money to repair it. That is s why overhead lines are used more often in the countryside because they are cheaper, can be repaired faster and have a longer life expectancy. Also, their energy transmission loss is smaller because they do not get as warm as the cables in the ground.



IMPACT ON NATURE

Transmission lines have a big impact on nature. They cut through the landscape and habitats, because the cables must never touch anything that is connected to the ground. Otherwise, there will be electrical flashovers which can lead to electrical shocks or fire. Also, noise and light emissions during the construction and the operation impact the nature.
Source: SOLAREIS [https://solareis.anl.gov/images/photos/transmissionROW.jpg]



IMPACT ON THE GROUND

Transmission lines have a big impact on the ground. The earth cables create indirectly cuts through the landscape because you can not build anything on top of them. The trees need to be at a certain distance, so that their roots do not damage the cables. Because of the heat that the earth cables create, there are speculations that the ground dries out and that the biodiversity decreases in the soil surrounding it.
Source: mbquadrat [https://mbquadrat.max-boegl.de/wp-content/uploads/2020/10/erdverkabelung-6.jpg]



IMPACT ON THE ECONOMY

Overhead lines take on so much space, that the land use underneath them is limited to agriculture. But even there, the use is restricted. Because of the poles it is more effort and less profit for the farmers than with normal fields. So, not only the land value under power lines decreases but also the land value surrounding them.



IMPACT ON THE PEOPLE

Overhead lines are visible from far away and change their surroundings. The opinions of people vary but many do not want them close to their property. A piece of land can thereby lose value if an overhead lines is built near it or on it.
Source: Baubiologie Magazin [https://baubiologie-magazin.de/site/wp-content/uploads/abstand-zwischen-haus-und-hochspannung-1.jpg]

SOURCES

- “Alle deutschen Stromanbieter auf einen Blick vergleichen” Strom-Report. Accessed 10 October 2022. https://strom-report.de/stromanbieter-deutschland/
- Dr. Rüdiger, Paschotta. “Supergrid” RP-Energie-lexikon. Accessed 10 October 2022. https://www.energie-lexikon.info/supergrid.html
- European Committee of the Regions. “Umweltauswirkungen von Hochspannungsleitungen” europa. Accessed 5 October 2022. https://op.europa.eu/en/publication-detail/-/publication/11c071a5-46a1-4ec9-bca4-c7a563dd59b0/language-de
- “GridMap” entsoe. Accessed 6 October 2022. https://www.entsoe.eu/data/map/
- “Hochspannungsleitungen (Freileitungen) als Elektrosmog-Quelle” Accessed 12 October 2022. https://www.bafu.admin.ch/bafu/de/home/themen/elektrosmog/fachinformationen/elektrosmog-quellen/hochspannungsleitungen--freileitungen--als-elektrosmog-quelle.html
- Kerstine, Appunn and Ruby, Russell “Set-up and challenges of Germany’s power grid” clean energy wire. Accessed 10 October 2022. https://www.cleanenergywire.org/factsheets/set-and-challenges-germanys-power-grid
- Larissa, D. Biasotto. “Power lines and impacts on biodiversity: A systematic review” Science direct. Accessed 10 October 2022. https://www.sciencedirect.com/science/article/pii/S0195925517304432
- Mareike, Sassenscheidt. “Energiewirtschaft in NRW” WIRTSCHAFT.NRW. Accessed 5 October 2022. https://www.wirtschaft.nrw/energiewirtschaft-nrw
- “Stellungnahme zum "Umweltauswirkungen von Hochspannungsleitungen” European Committee of the Regions. Accessed 10 October 2022. https://op.europa.eu/en/publication-detail/-/publication/11c071a5-46a1-4ec9-bca4-c7a563dd59b0/language-de
- Stromerzeugung im 1. Halbjahr 2022: 17,2 % mehr Kohlestrom als im Vorjahreszeitraum (https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/09/PD22_374_43312\.html;jsessionid=DB9653E7CD840E1751D106D8750CFBDF.live732)
- “Strom Import und Export Tabelle” Accessed 12 October 2022. https://www.stromdaten.info/ANALYSE/importexport/index.php
- “Transportverluste” Bürgerdialog Stromnetz. Accessed 10 October 2022. https://www.buergerdialog-stromnetz.de/frage/transportverluste/

This work by Timon Droll, Charis Gersl, and Flavio Thommen was created as part of the design studio Power to the People at ETH Zurich in Fall 2022. The PDF is intended for educational purposes only. Its commercial distribution is strictly forbidden.

© 2024, Architecture of Territory

Architecture of Territory
Professor Milica Topalović

TEACHING TEAM
Muriz Djurdjevic
Dorothee Hahn
Milica Topalović
Jan Westerheide

Prof. Milica Topalović
ETH Zurich
ONA G41
Neunbrunnenstrasse 50
8093 Zurich
Switzerland
+41 (0)44 633 86 88
www.topalovic.arch.ethz.ch