Rotterdam School of Management
Erasmus University

Case Development Centre
FOUNDED BY
Rotterdam School of Management
Erasmus University

Going Greener and Smarter:
The Energy Transition at the Port of Rotterdam's Industrial Complex

RSM - a force for positive change

7 AFFORDABLE AND CLEAN ENERGY

Introduction

The bustle and energy of a big port always amazes the visitor, and the Port of Rotterdam was no exception. Europe's largest seaport teemed with energy, and not just due to the massive cranes loading and unloading thousands of containers from huge cargo ships or the buzzing trucks connecting Rotterdam to a vast logistics network. In and around the Port of Rotterdam and its industrial complex, energy was being produced, stored, traded and reprocessed into products like fuels and chemicals.

The Port of Rotterdam and its industrial complex held a strong market position in 2019. Thanks to a turnover of €706.6 million in that year,[1] it started the new decade with a well-founded sense of optimism. The Port expected that its position would remain stable in the coming years, yet it knew that long-term success could not been taken for granted. With sustainability high on the public agenda, and with the government determined to curb CO_2 emissions to comply with the Paris Climate Agreement (**Appendix A**), the Port of Rotterdam realised that in order to stay competitive it needed to find more sustainable ways of powering its energy-intensive operations. With its enormous size and the myriad of sectors and operators active at the Port, such a comprehensive shift was going to be a huge and complex challenge.

In 2018 the Port of Rotterdam was responsible for almost 20% of total greenhouse gas emissions in the Netherlands, and each year the Port's marine transport pumped out 21.5 million tonnes of CO_2. To comply with the Paris Climate Agreement and to contribute to United Nations' Sustainable Development Goal of Affordable and Clean Energy (SDG 7), the Port of Rotterdam needed to reduce its greenhouse gas emissions by 95% by 2050 and transition fully to renewable energy.

The Port and its industrial cluster had already begun to initiate various projects to facilitate this shift, such as using green hydrogen to generate electricity and replacing gas-powered heat with residual heat from industrial processes. But surely there were many more opportunities waiting to be discovered and exploited, given the broad scope of the Port's industrial activities. What were these possible opportunities? How could the Port use them to create a new system for efficient and sustainable energy generation and use, so that existing Port activities would have a future and the industrial complex would remain a vibrant economic hub?

This case was developed by Kassiani Nikolopoulou and Michelle van Koert under the supervision of Dr. Yashar Ghiassi-Farrokhfal and Mohammad Ansarin at the Rotterdam School of Management (RSM), Erasmus University. The authors would like to thank Tao Yue at the RSM Case Development Centre for her input.

This case is part of the RSM Sustainable Development Goals (SDGs) case series. It is based on published sources and is written to provide material for class discussion rather than to illustrate either effective or ineffective handling of a management situation.

About the Port of Rotterdam

The Port of Rotterdam was located in the city of Rotterdam in South Holland, the Netherlands. With a total throughput of 469 million metric tonnes of goods and materials and a total market share of 36.8% in 2018, it was the largest seaport in Europe. Covering 105 square kilometres, the Port of Rotterdam stretched over a distance of 40 kilometres and facilitated the needs of over 50 million consumers throughout the European continent. The Port's most important operations were largely CO_2- and energy-intensive sectors, namely the petrochemical industry and general cargo trans-shipment handlings. The harbour also served as an important transit point for bulk and other goods between Europe and other parts of the world.

In 2017 the Port of Rotterdam provided direct and indirect employment to 385,000 people in businesses throughout the Netherlands, with 121,800 people directly employed at the Port. Over 55% of its revenues in 2015 came from the 120 companies comprising its industrial cluster (**Appendix B**). The Port's added value amounted to more than €45.6 billion in 2017 (last known figure), which was equal to 6.2% of the Dutch gross domestic product (GDP).[2]

Towards More Sustainable Operations

The Port was managed and operated by the Port of Rotterdam Authority, an unlisted public limited company with two shareholders: the Municipality of Rotterdam (approximately 70% of ownership) and the Dutch government (approx. 30%).[3]

The aim of the Port Authority was to enhance the Port's competitive position as a logistics hub and industrial complex, but also to manage and run the Port in a sustainable way. In fact, together with safety and accessibility, sustainability was one of the three strategic themes around which its business operations revolved. In that respect, the Port was committed to combatting climate change and wished to play a leading role in the worldwide energy transition. The reduction of CO_2 emissions and the efficient use of raw and residual materials were important tasks for the Port Authority.

Several important steps had already been taken in that direction. In its 2018 report "In three steps towards a sustainable Rotterdam-Moerdijk industrial cluster in 2050", the Port described the concrete steps the industry should take in the region to help achieve the climate objectives and become emission-free by 2050:

- Step 1: Take efficiency measures, use residual heat to heat homes and greenhouses, and capture CO_2 to store beneath the North Sea. Develop and scale up sustainable technologies, such as creating hydrogen through electrolysis.
- Step 2: Switch from oil and gas heating to electricity and hydrogen (generated with green electricity instead of natural gas).
- Step 3: Replace fossil fuels with biomass. Recycle 'waste' and use sustainably produced hydrogen.

This last step essentially envisioned a new system for raw materials and fuels in a circular economy. Innovation, recycling and industrial symbiosis, through the exchange of products and residual flows, could create value for the Port of Rotterdam, allowing it to become a circular port.

Following the report's rationale, a number of projects aiming to bring the Port in line with the Paris Climate Agreement were underway:

Hydrogen project H-Vision

In 2019, a consortium of 16 companies and organisations under the guidance of Deltalinqs, an association of businesses active at the Port of Rotterdam, carried out a feasibility study on the large-scale production and utilisation of blue hydrogen[a] in the harbour using natural gas and refinery fuel gas.

H-Vision, as the project was named, was set up to realise four steam-reforming plants, at a total capacity of 150,000-200,000 Nm^3 of hydrogen per hour, store the CO_2 under the North Sea and deliver the hydrogen to industrial parties in the harbour. The blue hydrogen could subsequently be used as a low-carbon energy carrier in industrial processes in order to generate high temperatures or to produce electricity. The first plant was planned to open in 2025, and the hydrogen produced would be transported to parties within the harbour or elsewhere in the Netherlands. The final goal was to capture and store eight megatonnes of CO_2, which required the cooperation of power plant owners in the harbour. The consortium tried to present a hydrogen strategy for the entire Netherlands – which in the future could include, for example, green hydrogen[b] from the northern Netherlands – and to contribute to the CO_2 reduction required to meet the Paris Climate Agreement goals.[4]

Green hydrogen, which was produced via electrolysis using power from renewable sources like offshore wind farms, generated zero CO_2 in its production. However, in 2020 there was not enough green electricity to produce green hydrogen on an industrial scale. Even so, the infrastructure for H-vision would make it easier to incorporate green hydrogen in the system over time. In that respect, H-vision offered two important benefits: reducing CO_2 emissions in the short term and accelerating the energy transition by paving the way for the future green hydrogen economy.[5]

Residual heat network

In early 2017 The Port of Rotterdam Authority, the Province of South Holland (provincial administration), energy companies Eneco and Gasunie, and the Rotterdam Heating Company (*Warmtebedrijf Rotterdam*) started developing a heat transmission grid in the province of South Holland that would use the residual heat

---

[a] 'Blue hydrogen' or 'low-carbon hydrogen' is obtained by converting natural gas at high temperatures. That means there is still CO_2 produced, but it is captured and stored instead of being released. This is also called CCS: Carbon Capture & Storage.

[b] Green hydrogen, also known as 'renewable hydrogen', is hydrogen that is produced with sustainable energy. The best known is electrolysis, in which water (H2O) is split into hydrogen (H2) and oxygen (O2) via green electricity

produced by various Port-based companies. The delivered heat would replace the use of natural gas in households, businesses and greenhouses, and less gas would be needed from Groningen in the north of the Netherlands[c].

This collaboration, named South Holland Heat Alliance, aimed to bundle existing and new pipelines into a regional heat distribution system for the province of South Holland. All parties were free to supply heat to, or source heat from, this open distribution network, which would be supervised by an independent network manager. The heat would then be transported to households, greenhouses and businesses by various distribution companies. According to the Heat Alliance's estimations, residual heat generated in the Port of Rotterdam alone could potentially fulfil the annual heat requirement of over 500,000 households. This would yield an annual reduction in CO_2 emissions of over one million tonnes.[6]. Apart from heat generated by industrial activity, the South Holland Heat Alliance was also examining geothermal sources and biogas. The first deliveries of heat to customers were expected to take place in 2023.

Although the road to sustainability was long, some of the Port Authority's efforts had already started to bear fruit, for instance the CO_2 footprint improvement. In 2018 the Port's CO_2 footprint was 7.3 kilotonnes. In particular, direct CO_2 emissions fell from 6.8 kilotonnes in 2016 to 5.9 kilotonnes in 2017 and to 4.5 kilotonnes in 2018. This meant that the 20% reduction objective (compared with 2016) had been achieved.[7]

Energy Production and the Energy Transition

Rotterdam was not only the import harbour for raw materials for the region; the Port also served as an energy hub for the arrival, production and distribution of energy streams in northwestern Europe. Its existing infrastructure consisted of a combination of conventional and sustainable energy sources: coal, natural gas, biomass, heat, steam, wind and solar energy. Three coal-fired power stations, one biomass power station and three gas-fired power stations were located at the Port. Additionally, heat, steam and CO_2 released via the industrial processes were exchanged through pipelines to cover the needs of chemical companies, greenhouse farming and households in the region.

Taking into consideration the importance of the Port as a hub for the energy and petrochemical sectors, as well as the need for sustainable growth, in 2016 the Port of Rotterdam Authority introduced its Energy Transition programme with the aim of transforming the Port and its industrial complex into a carbon-neutral cluster.

To better understand the challenges ahead, in 2017 the German Wuppertal Institute for Climate, Environment and Energy developed different scenarios for the

[c] The Groningen gas field in the Netherlands is the largest onshore natural gas field in Europe. Tremors caused by drilling had damaged buildings and had already led to a decision in 2013 to lower the output after protests by residents. In 2018 a strong earthquake associated with the gas field operations prompted the governement to promise to end production by 2030.

decarbonisation of the Rotterdam Port and industrial cluster on behalf of the Port of Rotterdam Authority. The decarbonisation scenarios described how CO_2 emissions could be reduced by 75-98% by 2050 as compared to 2015. According to the study, the transition to carbon-neutral industry and logistics was possible while continuing to supply products for which there was still demand, such as fuels and chemical products. Furthermore, the study presented four transition pathways and concluded that a combination of all four was the most viable solution.

In the first scenario, 'Business as Usual', the implementation of 'best available technology' would result in improved efficiency in the industrial sector, thereby lowering emission levels. Additionally, due to reduced demand for fuels, production was expected to decrease. This scenario would bring a decrease of 30% in CO_2 emissions by 2050, but it would still not allow the industry to meet the targets outlined in the Paris Agreement.

The second scenario, 'Technological Progress' would amount to a 75% reduction of emissions by relying on the large-scale capture and storage of CO_2.

The third scenario, 'Biomass and CSS' would focus on a combination of carbon capture and storage and the use of biomass as a feedstock for chemical production, leading to a potential CO_2 reduction of 98%.

The fourth scenario, 'Closed Carbon Cycle', also had a potential of 98% CO_2 reduction, based on using almost entirely recycled fossil fuel resources.

A Closer Look at the Energy Transition

The term 'energy transition' refers to the shift from the current energy production and consumption systems, which rely primarily on non-renewable energy sources such as oil, natural gas and coal, to a more efficient, lower-carbon energy mix. Reasons for this shift are the rising demand, technological innovation, geopolitical shifts and environmental concerns.

This type of transition is not new. The energy sector has undergone transformations in the past, for example due to the introduction of coal in the mid-19th century and then oil in the mid-20th century and nuclear power in the 1970s. However, it is worth noting that these new forms of energy added to, rather than replaced, existing sources.[8]

Although one could argue that energy systems have always been in transition, today's shift is unprecedented due to the scale of the modern energy system and the urgency of the transition. According to a 2018 special report of the Intergovernmental Panel on Climate Change, global anthropogenic emissions will need to drop to net zero by 2050 to limit the global temperature increase to less than 1.5°C above the pre-industrial level.[9] The energy system accounts for two-thirds of all global emissions, and thus the decarbonisation of the energy sector is paramount to mitigating the effects of climate change. It is estimated that renewable energy and energy efficiency measures can potentially achieve 90% of the required carbon reduction.[10]

Despite the global milestone of political commitment achieved through the Paris Agreement, numbers showed that the energy transition worldwide had slowed. According to the World Economic Forum's 2019 report, investment in fossil fuels as a share of total energy supply investment grew in 2017 for the first time since 2014. Moreover, the share of fossil fuels in total primary energy supply had remained stable at 81% for the past three decades. The same view was echoed in the European Commission's 'Energy Roadmap 2050', which already in 2011 indicated that the growth of renewable energy would slacken after 2020 unless there was further intervention.

In the Netherlands, on 28 June 2019, the government presented the new climate agreement (*Klimaatakkoord*) with the aim of reducing national CO_2 emissions by 49% by 2030 compared to 1990 levels. Among other things, the climate agreement meant that all coal plants in the Netherlands would be closed or converted into biomass plants in due course, new wind farms in the North Sea up to 49 TWh would be established, a substantial hydrogen development programme would be implemented for the large-scale production and storage of renewable electricity, and industrial clients would face higher energy taxes than households. The Dutch government had previously failed to meet the reduction goals for 2020 in view of the Paris Agreement of December 2015, and with the new agreement it seemed recommitted to reaching the target.

While the energy transition was underway, further action was needed at the global, regional and local scale. Technological innovation, supporting policy frameworks and market instruments were all enabling factors towards this direction.[11] Organising the energy transition called for new forms of collaboration, governance and financing.

From Traditional to Smart Power Grids

The shift towards renewable energy sources and efficiency measures had far-reaching consequences for the national energy infrastructure; the energy transition required a new energy model.

With the introduction of renewable energy sources, the traditional grid-based electricity network was starting to fragment. In addition to the remaining coal-powered plants, wind turbines and solar panels in and around the Port of Rotterdam were connected to the grid, resulting in an increasingly decentralised network. As sustainable energy depended on weather conditions, its supply was extremely irregular. Therefore, a smart network was needed that would align supply with demand at all times.

The increasing use of solar panels and wind turbines was also transforming power generation, transmission and distribution. Now consumers of power were also becoming producers, giving rise to the concept of 'prosumers'. Technological developments such as smart technologies, automation and the Internet of Things (IoT) allowed for two-way communication between the grid and customers. As a result the grid needed to be intelligent enough to respond to the changing demand in real time, for example by adjusting prices to incentivise energy consumers to reduce consumption during peak periods and perhaps store energy temporarily.

Moreover, a peak in electricity demand was expected in the near future, as the electrification of industrial processes, the production of green hydrogen and electric transport all required green and other electric power. In the case of the Port of Rotterdam specifically, demand was predicted to increase by a factor or two and possibly even four. This meant that Rotterdam had to reinforce its power grid while there was only limited space for additional infrastructure. The two grid operators, Stedin and TenneT, together with the Port Authority, explored a variety of technical alternatives and came up with recommendations such as using locations directly along the coast for the large-scale conversion of electric power (generated using offshore wind) into hydrogen and other energy carriers.

In 2013 the Port of Rotterdam started investigating the 'Smart Grid' concept as a new energy model to reduce the dependence on traditional grids and the risk of supply interruptions. A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources (renewable or otherwise) to meet the varying demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability.[12] Examples of smart grid technologies include smart energy meters, digitised electricity networks with smart algorithms, and network sensors that monitor the levels and quality of tension.[13]

Due to the high energy demand of its industrial complex and the limited space, the Port of Rotterdam needed to modernise its energy system by tapping into its cluster advantages further. Industrial clients could pool the energy resources available to them and maybe even move towards operating a 'micro-grid' with each community of industrial customers.[14]

Smart Grid Applications

If Thomas Edison and Alexander Graham Bell were somehow transported to the 21st century, Bell would hardly be able to recognise the components of today's communications systems, though Edison would still be able to recognise almost all of the major components in today's electricity grid system. Consequently, one could argue that the existing electrical power system needed a lot of design improvements and vital upgrades to cope with 21st century needs[15]. It was exactly this modernisation of the electricity system that the deployment of smart grid technologies connoted.

Characteristics

Although there were different definitions of smart grids, one could identify the following functional characteristics:[16]

- Self-healing from power disturbance events;
- Enabling active participation by consumers in demand response;
- Operating resiliently against physical and cyber attack;
- Providing quality power for 21st century needs;
- Accommodating all generation and storage options;
- Enabling new products, services and markets; and
- Optimising assets and operating efficiently.

ICT

In general, a smart grid was understood to be the combination of a traditional distribution network and a two-way communication network for sensing, monitoring and dispersing information about energy consumption.

A typical smart grid consisted of numerous power generating entities and power consuming entities, all connected through a network (**Appendix C** illustrates an example of communication architecture in a smart grid). The generators fed the energy into the grid, and consumers drew energy from the grid. Real-time, dynamic and decentralised energy distribution were hallmarks of smart grids.

An essential feature of a smart grid was the use of information and communication technology to gather and act on information in an automated fashion to improve the efficiency, reliability, cost effectiveness and sustainability of the production, transmission and distribution of electricity.

Customer participation & behaviour

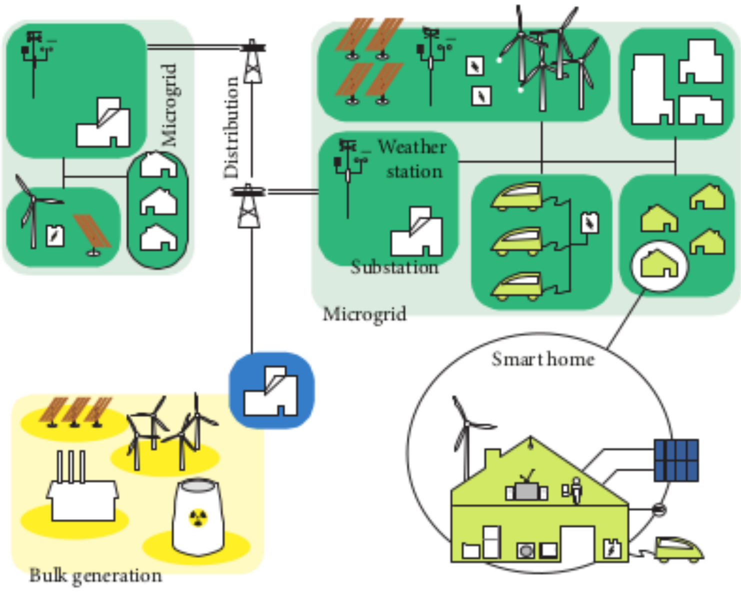
One main component of the smart grid was the possibility of customer participation in the overall grid energy management. This participation was achieved either via demand response or demand-side management, in which a power company provided incentives for customers to shift their load over time (e.g. lower pricing or coupons), and customers were provided with partial autonomy to participate in the buying and selling of energy from and to the grid.

In any smart grid mechanism, demand response models and their associated challenges had to be factored in. For example, one of the key challenges of designing demand-side management models included the need for modelling customer behaviour. Other challenges included modelling customer participation, developing decision-theoretic tools, optimising pricing, incorporating time-varying dynamics (e.g. fluctuating demand), and accounting for power grid constraints.

Distribution network

Thanks to recent technological advancements on distributed energy resources management, the smart microgrid distribution network emerged (**Exhibit 1**). A microgrid was an electrical energy distribution network that included a cluster of loads, distributed generators (e.g. renewable energy sources such as solar panels and wind turbines), transmission and energy storage systems.

Exhibit 1: Conceptual Illustration of a Microgrid



Source: Bari, A., Jiang, J.,Saad, W., et al.(2014)

A microgrid could dynamically respond to the changes in energy supply by self-adjusting the demand and generation. Microgrids were considered to be the building blocks of future smart grids with their integration of multiple small-scale renewable energy sources.

A microgrid could be coupled with the utility power grid through a single connection, known as a point of common coupling. The electrical energy could flow in either direction through this coupling, based on the available energy generated within the microgrid and the demands of the consumers within the microgrid.

In this way, a microgrid user could take power from the utility grid at times when not enough power was generated within the microgrid, or when the price of the utility grid power was cheaper. On the other hand, any excess power generated by energy sources in the microgrid could also be fed into the utility grid.

A microgrid, when disconnected from the main grid, was known as an 'islanded microgrid'. In an islanded microgrid operation, distributed generators (DGs) continued to power the users of the microgrid without their needing to obtain electric power from the utility grid.

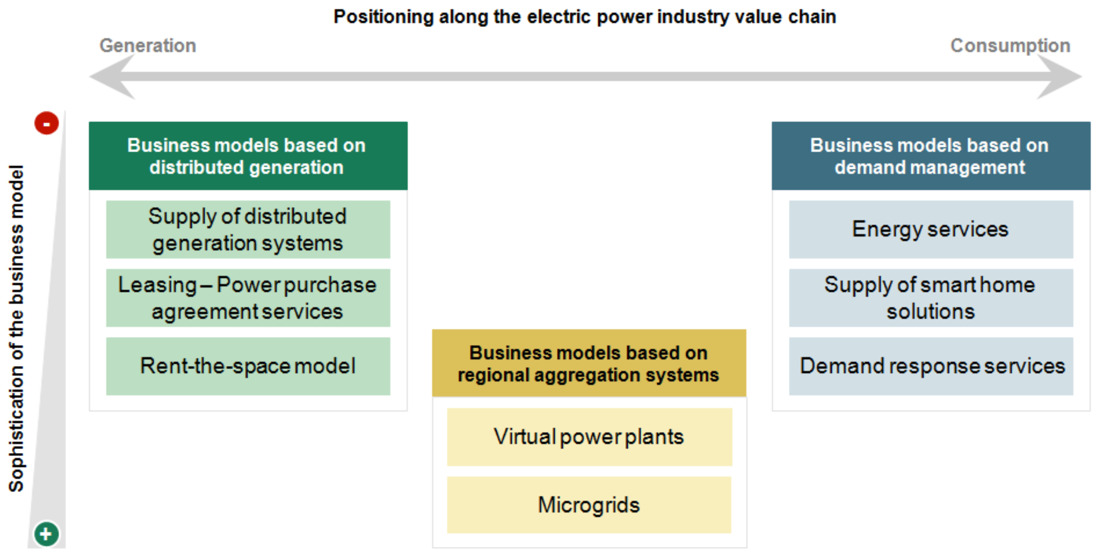
The benefits of microgrids were numerous. They could increase the reliability of power supply locally through active control of internal loads and generations. They could incorporate renewable energy sources, which helped to reduce environmental pollution; they could limit feeder losses, improve voltage quality and provide uninterrupted power supply.

With the advancement of technology, smart grids opened up many opportunities. Reaping the full benefits of the smart grid was dependent upon tackling a number of challenges (e.g. communication infrastructure and energy management) and risks (e.g. consumer privacy issues and cyber-attacks).

Changes in the value chain

The new paradigm of electric power generation and consumption was also transforming the sector's value chain. From centralised one-way demand and supply, it was now moving towards more decentralisation and allowed for two-way communication. Additionally, the fragmentation brought about by the rise of renewable resources also meant that the value chain, which had always been vertically integrated around utilities, was becoming increasingly fragmented, thus making way for new players – including consumers themselves – to join at different points along the value chain (**Exhibit 2**).

Exhibit 2: Smart Energy in the Electric Power Industry Value Chain



NB: Supply of generation systems includes the supply of accessories such as storage systems, batteries and solutions to optimize energy generation.
NB 2: The level of sophistication was assessed according to the complexity of each business model and its added value for end-customers.

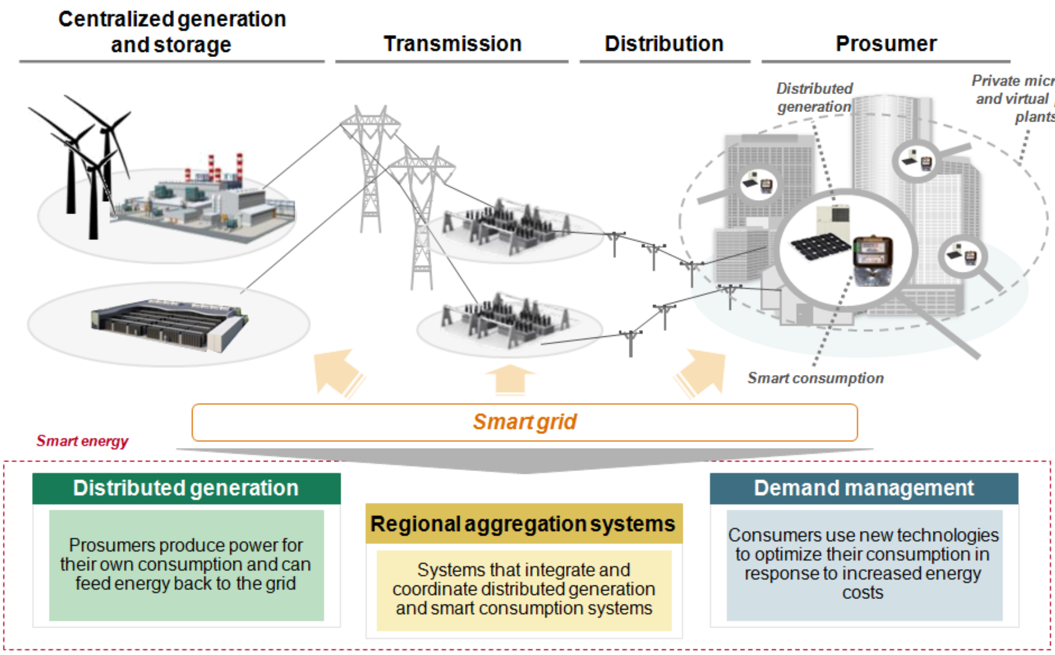
Source: Energy Chair of Orkestra, Boston Consulting Group (2015). Smart Energy: New Applications and Business Models.

Following the traditional structure of the power industry value chain, three major business model categories could be identified (**Exhibit 3**):

- Distributed power generation;
- Energy demand management; and
- Regional aggregation systems (a combination of applications from the first two).

The last category was the most relevant in the case of the Port of Rotterdam. Regional aggregation systems, i.e., virtual power plants and microgrids, encompassed both generation (they included distributed generation systems) as well as demand (they often included solutions to control and optimise power consumption).

Exhibit 3. Smart Energy Business Models



Source: Energy Chair of Orkestra, Boston Consulting Group (2015). Smart Energy: New Applications and Business Models.

The objective of a virtual power plant was to relieve the load on the grid by smartly distributing the power generated by the individual units during periods of peak load. Additionally, the combined power generation and power consumption of the networked units in the virtual power plant was traded on the energy exchange.[17]

Microgrids were local and regional electric power systems, composed of distributed generation sources and controllable loads, which operated individually and autonomously, in parallel or isolated from the existing network.[18] This type of smart grid was also aligning supply and demand within subsystems by managing them as a whole.

The position of virtual power plant operators, or *aggregators*, was crucial in demand response services and in the management of virtual power plants and microgrids, since they served as facilitators and coordinators between different sources of generation and/or points of consumption.

Although they included both aggregated and optimised energy generation and distribution, microgrids had a very defined network boundary and a very specific area that they served. Additionally, microgrids could disconnect from the main grid. Virtual power plants, on the other hand, often covered a wider area and were flexible enough to expand or decrease the area in which they operated, depending on market conditions. They served the main grid, while microgrids did not always provide services to the main grid.

Business models

The virtual power plant business model was organised around aggregators. These virtual power plant operators sold power through bilateral contracts with grid operators or utilities, or on the wholesale electricity market. Aggregators combined the power production capacity of a number of large prosumers (i.e., businesses and large institutions). In the event of supply-demand imbalance, virtual power plant managers combined the power generated and available from virtual power plants and fed it into the power grid.

In this model for selling power, virtual power plant operators could be compensated according to the capacity made available to the grid operators or utilities (€/MW) or the amount of power supplied (€/MWh), which would be paid at a price established in the contract or by the wholesale electricity market. In turn, aggregators offered similar payments to prosumers who made their power generation capacity available.

In microgrids there were two sources of generation: prosumers and small distributed generation plants. These were supported by storage systems which rendered microgrids more autonomous. The power generated was used either by prosumers or for other modes of consumption (e.g. public lighting in urban areas). Microgrids could function as isolated units or as part of a traditional distributed energy network.

In the latter case, microgrids could prevent interruptions in energy generation by switching to the traditional grid. Furthermore, when microgrids surpassed their ability to store power, they could feed surplus power back into the traditional grid, possibly in exchange for payment.

In the microgrid business model, consumers paid to be connected to the microgrid and for their consumption, with consumption possibly being adjusted according to the power produced and fed back into the microgrid if the consumer was a prosumer. Revenue from consumers was used for infrastructure maintenance and management.

Examples of microgrid applications

The Bronsbergen Holiday Park microgrid in the Netherlands was one of the largest projects in the European Union. This microgrid fed 208 homes, its energy coming from 108 solar panels with a total peak generation of 315 kW. It was connected to the 10kV network, thanks to a 400 kVA transformer. The system had a storage centre consisting of two battery banks. It included central control for handling the data sent to the dispatch, a measurement and monitoring centre of all system variables, and an automation system for the operation of the microgrid, whether it was independent from or connected to the network.[19]

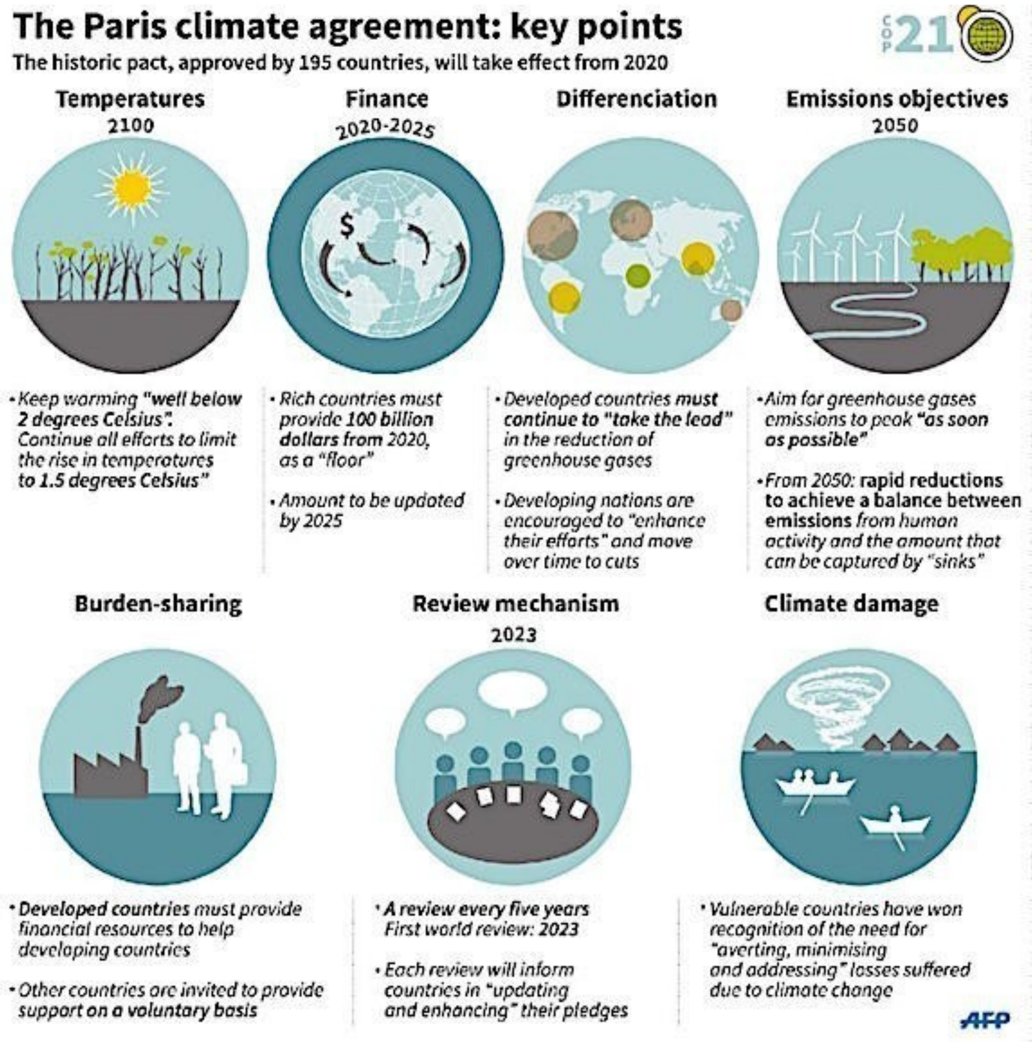
Decentralised energy was a common blockchain application in 2019. The technology's capabilities were tested by a number of big energy players, such as the German utility EnBW, the French multinational energy company Total, and State Grid EV service Co., a subsidiary of the world's largest utility firm, State Grid Corporation of China.[20] That same year, the Port of Rotterdam's blockchain incubator, BlockLab, also started a pilot using blockchain for the energy grid. The idea was that the application would serve as a trading platform to trade price incentives so as to use energy efficiently. The trade could furthermore be automated by establishing 'smart contracts', in other words a collection of logical rules that enabled decision-making processes to be automated. In this scenario, if the energy price exceeded a certain value, one could opt to automatically switch to energy from a charged battery instead.[21]

Conclusion

The Port of Rotterdam and its industrial complex had already taken steps to align their operations with the sustainability imperative that was now becoming more and more salient not only in government circles but among consumers as well. At the same time, the industrial complex had to remain an attractive and profitable destination for businesses to settle in. Different stakeholders, such as energy companies, industrial clients, households and regional governments, with different priorities and limitations, needed to be considered throughout the energy transition to a carbon-neutral economy. Smart technologies, automation and the IoT were enabling factors in that direction, as well as the public-private sector partnerships and consortia that had been formed in previous years.

Looking further into the future, what business cases could the Port of Rotterdam and its industrial complex develop to engage energy consumers in such a way that the Port's goals regarding energy transition would be met? When developing the business cases, how could the needs and constraints of different stakeholders be taken into consideration? And based on the business cases, what applications (apps) could be further developed as solutions to various challenges surrounding sustainable development and the circular economy?

Appendix A: The Paris Climate Agreement



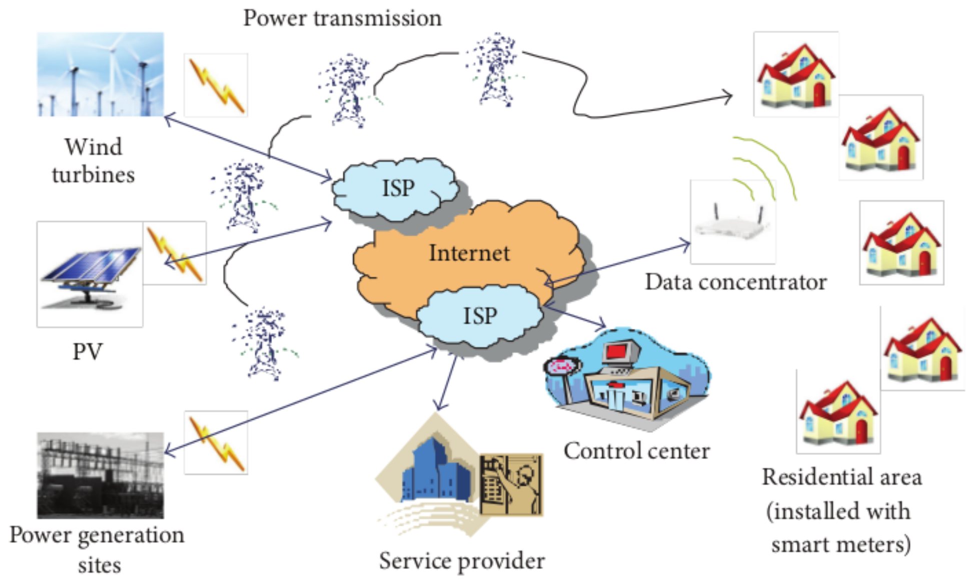
Source: World Economic Forum
https://www.weforum.org/agenda/2016/11/5-charts-that-explain-the-paris-climate-agreement/

Appendix B: Companies in the Rotterdam Energy Industrial Cluster

The industrial cluster in Rotterdam comprises:
Oil refineries
Crude oil terminals
Chemical and petrochemical companies
Third-party tank storage and distribution terminals for chemicals, biofuels and edible oils
Ship-to-ship transfer facilities
Refineries for edible oils
Biofuel manufacturers
Power plants
Natural gas terminals
Industrial gases and water companies
Steam and power companies
Over 1,500 km intercompany pipeline network for oil and chemical products
Specialised warehousing companies for hazardous goods
Tank cleaning companies
Utility companies
Waste incineration and disposal companies
Comprehensive range of ancillary service companies

Source: Port of Rotterdam
https://www.portofrotterdam.com/sites/default/files/facts-figures-energy-port-and-petrochemical-cluster.pdf?token=vHfZySB6

Appendix C: An example of communication architecture in a smart grid



Source: Bari, A., Jiang, J., Saad, W., et al. (2014). Challenges in the smart grid applications: an overview.

References

Bari, A., Jiang, J., Saad, W., et al. (2014). Challenges in the smart grid applications: an overview. International Journal of Distributed Sensor Networks. https://doi.org/10.1155/2014/974682

Cassiani, C., Candelo-Becerra, J, & Hoyos Velasco, F.(2020). Electricity market strategies applied to microgrid development. International Journal of Power Electronics and Drive Systems (IJPEDS). http://doi.org/10.11591/ijpeds.v11.i1.pp530-546

Energy Chair of Orkestra, Boston Consulting Group.(2015).Smart Energy: New Applications and Business Models. Retrieved from https://www.orkestra.deusto.es/images/investigacion/publicaciones/smart_energy_en_15072015.pdf

International Renewable Energy Agency. (nd). Energy transition. Retrieved from https://www.irena.org/energytransition

Ledger Insights (2019). Big names make up Energy Web Foundation's 100 strong blockchain ecosystem. Retrieved from https://www.ledgerinsights.com/blockchain-energy-web-foundation-ewf-100/

Next.(nd). Virtual power plants.How to network distributed energy resources. Retrieved from https://www.next-kraftwerke.com/vpp/virtual-power-plant

Planete Energies (Jan. 7, 2015). The challenges of the energy transition. Retrieved from https://www.planete-energies.com/en/medias/close/challenges-energy-transition

Port of Rotterdam (nd). Facts and Figures 2019. https://www.portofrotterdam.com/en/our-port/facts-figures-about-the-port

Port of Rotterdam (nd). Highlights Annual Report 2019. Retrieved from: https://www.portofrotterdam.com/en/port-authority/about-the-port-authority/finance/annual-reports

Port of Rotterdam (nd). Highlights Annual Report 2018. Retrieved from: https://www.portofrotterdam.com/en/port-authority/about-the-port-authority/finance/annual-reports

Port Strategy (Sept. 17, 2013). Rotterdam takes Smart Grid plunge. Retrieved from https://www.portstrategy.com/news101/port-operations/planning-and-design/rotterdam-climate-initiative2

TU Delft (nd).Fresh light on the energy network of the future.Smart Grids. Retrieved from https://www.tudelft.nl/en/tpm/research/projects/smart-grids/

United Nations Economic Commission for Europe. (2015). Electricity System Development:A Focus On Smart Grid. Overview of Activities And Players In Smart Grids. Retrieved from https://www.unece.org/fileadmin/DAM/energy/se/pdfs/eneff/eneff_h.news/Smart.Grids.Overview.pdf

Van Cappellen, L., Croezen, H., Rooijers, F. (July 2018). Feasibility study into blue hydrogen. Technical, economic & sustainability analysis. Delft. CE Delft. Retrieved from: https://www.cedelft.eu/en

World Economic Forum. (March 2019). Fostering Effective Energy Transition. 2019 edition. Retrieved from http://www3.weforum.org/docs/WEF_Fostering_Effective_Energy_Transition_2019.pdf

Endnotes

1 Highlights Annual Report 2019. https://www.portofrotterdam.com/en/port-authority/about-the-port-authority/finance/annual-reports

2 Highlights Annual Report 2018. https://www.portofrotterdam.com/en/port-authority/about-the-port-authority/finance/annual-reports

3 https://www.portofrotterdam.com/en/port-authority/about-the-port-authority/organisation/organisation

4 Van Cappellen, L., Croezen, H., Rooijers, F. (July 2018). Feasibility study into blue hydrogen. Technical, economic & sustainability analysis. Delft. CE Delft. Retrieved from: https://www.cedelft.eu/en

5 More on the Port of Rotterdam's Hydrogen Vision (May 2020). https://www.portofrotterdam.com/sites/default/files/hydrogen-vision-port-of-rotterdam-authority-may-2020.pdf?token=XHpe4PNr

6 https://www.euroheat.org/news/main-infrastructure-south-holland-heat-network-gaining-shape-leiden-region/

7 Facts and Figures 2019. https://www.portofrotterdam.com/en/our-port/facts-figures-about-the-port

8 https://www.planete-energies.com/en/medias/close/challenges-energy-transition

9 http://www3.weforum.org/docs/WEF_Fostering_Effective_Energy_Transition_2019.pdf

10 https://www.irena.org/energytransition

11 Ibid.

12 https://www.unece.org/fileadmin/DAM/energy/se/pdfs/eneff/eneff_h.news/Smart.Grids.Overview.pdf

13 https://www.tudelft.nl/en/tpm/research/projects/smart-grids/

14 https://www.portstrategy.com/news101/port-operations/planning-and-design/rotterdam-climate-initiative2

15 Bari, A., Jiang, J., Saad, W., et al. (2014). Challenges in the smart grid applications: an overview. International Journal of Distributed Sensor Networks. https://doi.org/10.1155/2014/974682

16 United Nations Economic Commission for Europe. (2015). Electricity System Development:A Focus On Smart Grid. Overview of Activities And Players In Smart Grids. Retrieved from https://www.unece.org/fileadmin/DAM/energy/se/pdfs/eneff/eneff_h.news/Smart.Grids.Overview.pdf

17 https://www.next-kraftwerke.com/vpp/virtual-power-plant

18 Cassiani, C., Candelo-Becerra, J, & Hoyos Velasco, F.(2020). Electricity market strategies applied to microgrid development. International Journal of Power Electronics and Drive Systems (IJPEDS). http://doi.org/10.11591/ijpeds.v11.i1.pp530-546

19 Cassiani, C., Candelo-Becerra, J, & Hoyos Velasco, F.(2020). Electricity market strategies applied to microgrid development. International Journal of Power Electronics and Drive Systems (IJPEDS). http://doi.org/10.11591/ijpeds.v11.i1.pp530-546

20 https://www.ledgerinsights.com/blockchain-energy-web-foundation-ewf-100/

21 https://mfame.guru/port-of-rotterdam-deploys-blockchain-for-energy-grid-and-logistics/