IW-NET

Innovation-driven Collaborative European Inland Waterways Transport Network

D2.6 – IW-NET Shore Power Solution

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Executive Summary

IW-NET is the acronym for the project "Innovation-driven Collaborative European Inland Waterways Transport Network", supported by the European Commission under the “Moving freight by Water: Sustainable Infrastructure and Innovative Vessels” topic of the Horizon 2020 research and innovation programme under grant agreement No 861377.

Even though being environmentally desirable, broad provision of onshore power supply (OPS) for inland vessels at berths comes with significant financial and also administrative burden for waterway and port infrastructure providers. Further, from the port user perspective the lack of harmonized and often non digitalized procedures for the use of available facilities place impediments towards stronger uptake. As a solution to this, the IW-NET project provides a blueprint for a cost-effective solution that may be used to upgrade legacy facilities and integrate the shore power process into a digital smart port ecosystem.

This deliverable aims at describing the IW-NET shore power concept from a technological as well as process and business perspective. One of the objectives to be achieved by the work described within this deliverable is to assess existing solutions as well as defining functional, technical and business requirements technological solutions for the upgrade of existing shore power stations. Next, a technological concept addressing these requirements is to be developed and then materialized. Ultimately, the works aims at a prototypical implementation of this concept in form of a functional demonstrator as well as a near-series demonstrator that has been installed within a real port environment. This provides the groundwork for later analysis within the IW-NET Application Scenario (AS) 2, which is placed in the Ports of Bremen.

Disclaimer

List of Abbreviations

Abbreviation / Term	Description
AC	Alternating Current
AFIR	Alternative Fuel Infrastructure Regulation
API	Application Programming Interface
AS	Application Scenario
ATA	Actual Time of Arrival
ATD	Actual Time of Departure
DIN	Deutsches Institut für Normung / German Institute for Standardization
EFIP	European Federation of Inland Ports (EFIP)
EMC	Electromagnetic Compatibility
GHG	Greenhouse Gases
IoT	Internet of Things
IWT	Inland Waterway Transportation
LoRa	Long Range (radio communication technique)
LPWAN	Low-Power Wide Area Network
LTE	Long Term Evolution (wireless broadband communication standard)
MIC	Message Integrity Code
MQTT	Message Queuing Telemetry Transport
NB-IoT	NarrowBand Internet of Things
NOx	Nitrogen Oxides
OPS	Onshore Power Supply
PM	Particle Matters
REST	Representational State Transfer
VDE	VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V.
WiFi	Family of wireless network protocols

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1 Introduction

1.1 Focus of the Deliverable

The facilitation and use of onshore power supply (OPS) represent important means to reduce direct GHG and pollutant emissions of inland vessels while staying at berth. This is especially important in dense urban areas with critical thresholds for air and noise pollution (Wisselmann & Kempmann, 2023). However today, the use of shore power in most parts of Europe is far from being the norm, while its use is often considered inconvenient and inefficient for the port users. From a port management perspective, the operation of shore power facilities often comes with significant financial and also administrative burden. As a solution to this, the IW-NET project aims to provide a blueprint for a cost-effective solution that may be used to upgrade legacy facilities and integrate the shore power process into a digital smart port ecosystem. The itself solution can be considered a process innovation that combines open-source software with standardized hardware to address the specific needs within port contexts.

This document provides a technical and conceptual description of the “IW-NET Shore Power Solution”. Besides an outline of the general problem and related requirements, it covers the conceptual design and architecture of the solution, both from a technical as well as from a process perspective. Furthermore, it describes a set of activities that are necessary for further implementation of the concept. As such, it can be seen as an amendment to other deliverables of the IW-NET project. Specifically, thematic overlaps with the following reports are of relevance:

- The technical concept provided in this report can be referred to as an IoT-based approach to shore power management. While this deliverable focusses on a specific application of this technological field, more general information on IoT sensors and gateways is presented in D1.3 and D1.4.
- Among other aspects, D2.4 and D2.5 provide detailed information on the IW-NET web application as a means to digitalize port call procedures in general. While shore power management has been described as a vital component of a digital port call process in these documents, the technological components that allow for the integration of shore power facilities have not been described in detail.
- The general problem, technical and business requirements as well as testing and evaluation of the solution is closely linked with the IW-NET application scenario 2 (AS2). Therefore, the report D4.3 provides detailed information on the evaluation of a near-series demonstrator.

The underlying work of this document has been carried out within project task 2.4, which is placed within the work package 2 (IWT Infrastructure Improvements and TEN-T, Sea and Inland Ports Integration) of the IW-NET project and was initially expected to run from project month 6 (October 2020) till project month 30 (October 2022) and got extended to month 36 (April 2023).

1.2 Mapping IW-NET Outputs

The purpose of this section is to map the commitments set out in the IW-NET Grant Agreement (GA), against the projects respective outputs that are presented in this deliverable. It also points out necessary changes to the scope of investigations.

Table 1: Adherence to IW-NET's GA Deliverables & Task Descriptions

DELIVERABLE	
D2.6 IW-NET shore power solution	Report on the IW-NET shore power solution design as well as features implementation plan and architecture description.

TASKS	
T2.4 IW-NET Shore Power Solution (M4-M36) Leader: BRE	Development of an application that facilitates the use and management of shore power services for inland vessels. User components include a real-time overview of berth occupancy as well as booking, activation and payment of shore power services. For infrastructure managers, the IW-NET shore power solution will make it possible to monitor current and predict future berth/power station occupancy, fully digitalize the invoicing process and thereby optimize the service level.

IW-NET GA Component Title	**IW-NET GA Component Outline**	**Respective Document Chapter(s)**
ST2.4.1 Design the shore power service application (ISL)	*"Analysis and monitoring of the current state-of-the-art in regard to shore power systems and processes as well as technological standards (i. e. DIN EN 15869). Use of an agile approach that is aligned to the AS3 lifecycle, gathering a backlog of requirements and acceptance criteria by closely engaging with vessel operators and infrastructure managers.* *Generate a continuous feature development plan that will be used as guideline for designing the functions. Creation of APIs and micro services that are linked to the IW-NET architecture components."*	2,3
ST2.4.2 Deploy the application for the new Power – Shore solution (ISL)	*"Deployment and configuration of a running version of the application. Interconnectivity with shore power hardware needs to be established. Basic acceptance tests and assessments will be performed in close collaboration to IW-NET industry stakeholders and in alignment with the AS2/3 lifecycle."*	4

2 Problem Description

2.1 Problem Description

Inland waterway transportation (IWT) is generally considered as an eco-friendly transport alternative compared to road transportation and therefore has an important role in the European Commission's (European Commission, 2020) Sustainable and Smart Mobility Strategy. Compared to road transport, IWT requires about one third of energy and thus GHG emissions per tonne-kilometre (European Environment Agency, 2017). However, from a pollution perspective, this ecological advantage is currently diminished by the use of often old diesel engines that cause comparatively high particle matter (PM) and nitrogen oxide (NOx) emissions (Pillot, Guiot, Le Couttier, Perret, & Tassel, 2016).

While on the long run, the IWT fleet needs to follow a pathway towards zero emissions, experts assume that the use fossil combustion engines will remain significant till 2050 (CCNR, 2022). This calls for intermediate actions. Besides the implementation of stricter regulations for the installation of new engines, this includes the provision and use of shore power in order to reduce direct emissions at berth. This is especially important in berthing areas located in dense urban areas, where pollution (including noise) may have a direct impact on quality of human life. However, the potentials of shore power in Europe are currently far from being fully utilized. As an example, the European Federation of Inland Ports (EFIP) estimates that only "20% or less of all berths in Europe" allow to use shore power (EFIP, 2022).

The are several possible reasons leading to this situation. From an infrastructure perspective, the landscape of infrastructure providers is rather fragmented and lasts from public berths managed by the member states waterway authorities to public/private berths in the responsibility of local port authorities or even private terminal operators. Especially for the private sector, an incentive framework for setting up shore power stations is currently missing, even in light of high investment as well as maintenance costs. Even though there currently exist companies that offer shore power solutions, such as Connect4Shore or Walstroom, the market has not accepted a common standard with respect to the service pattern (e. g. access, payment). With its proposal for the "Alternative Fuel Infrastructure Regulation" (AFIR) (European Commission, 2021a), which is part of the Fit for 55 package (European Commission, 2021b), the EU commission is increasing the pressure on infrastructure managing companies, requiring at least one installation per port within TEN-T corridors by 2025 and others until 2023. Another issue is the use of existing stations by port users, i.e., the skippers and vessel owners, where the lack of harmonized procedures is creating an additional barrier. Also, given high costs for electrical energy, is often more expensive than running auxiliary engines (European IWT Platform, 2022).

The solutions described within this deliverable is inspired by the environmental and business conditions of the IW-NET application scenario 2 (AS2), which is located within the ports of Bremen and Bremerhaven. Here, the local infrastructure management company bremenports GmbH & Co KG (BRE) currently maintains more than 20 public berths for inland vessels on behalf of the State of Bremen that are equipped with shore power stations. Access to these shore power facilities by skippers and barge owners is currently granted through a manual process, in which new port users are required to pick up a key at the port office. Power meters installed at the shore power stations need to be captured manually at the moment.[1] Therefore, infrastructure management must rely on the information provided by skippers as to whether these were really able to use shore power or not. Verifying the

[1] By January 2021, the mandatory use of shore power is subject to a flat rate fee. Therefore, meter readings must currently not be captured per port call. However, it is possible that this policy may be subject to change.

provided information leads to overheads outrunning the flat-rate for the provision of shore power. Given these conditions, the current solution is considered time and cost inefficient as it

- involves much staff capacity both from port management and port users,
- makes the provision of power non-transparent in terms of actual usage and costs,
- increases the administrative controlling process of the usage of power for infrastructure management
- increases the threshold for skippers that come to the port the first time to use shore power at all.

Existing solutions available on the market require the acquisition of entire shore power boxes, which results in significant investment costs and expenses. To the knowledge of the authors, there currently exists no cost-effective solution that allows to upgrade existing stations while meeting the functional, technical and business requirements as identified within the application scenario.[2] Thus, the development task within IW-NET T2.4 was to design a cost-effective retrofit solution for existing stations that allows for remote meter readings and remote access and thus a streamlined process. Given the need for better integration into a digital smart port ecosystem, the proposed solution not only relies on technical but on process innovation. For a more detailed description of the scenario, please refer to IW-NET D4.3.

Figure 1: Berth for inland vessels operated by bremenports (stc: bremenports GmbH & Co. KG)

2.2 Requirements

2.2.1 Technical Requirements

The technical requirements that were identified for the technical development of the IW-NET shore power solution have been collected based on expert consultations in and outside the consortium and especially the AS2 environment. Furthermore, two existing standards set by the German Institute for Standardization (DIN - German Institute for Standardization 2021) have been consulted, namely:

[2] See 2.2. A more detailed overview on available solutions in Europe is given in D4.3.

- DIN VDE 0100-709:2020-02 / VDE 0100-709:2020-02, Part 7-709, the principal norm, with regards to requirements for special installations or locations like harbours, marinas and similar locations as well as for special requirements for shore supply to ships,
- DIN EN 15869-1/2/3:2019-08 with regards to inland navigation vessels, electrical shore connection, three phase current 400 V, 50 Hz, up to 125 A. DIN EN 15869-1/2/3:2019-08 builds on its predecessor DIN EN 15869-1:2010-06. The latter has been revised in 2019. Full accordance with DIN EN 15869-1:2010-06 is given at the port of Bremen whilst the requirements of DIN EN 15869-1/2/3:2019-08 are only partly catered for. Investigations are underway to assure compliance to the revised norm (see DIN - German Institute for Standardization 2020, DIN - German Institute for Standardization 2019, DIN - German Institute for Standardization 2019a, DIN - German Institute for Standardization 2019b, Binnenschifffahrt 2019, DIN - German Institute for Standardization 2010)

In specific, the following technical aspects with regards to the upgrade of the existing stations need to be respected:

- Casing must be flame-resistant, firmly mounted and cannot be opened with standard tools
- Components must withhold ambient temperatures of -20° C to + 60° C
- Electromagnetic compatibility (EMC) must be guaranteed. This especially applies with respect to radio networks installed.
- Entire station must be IP54[3] protected, with the exception of the door / flap
- Solution must consist of components
    - specifically designed for industrial usage and adhere to applicable industry norms
    - that are easily replaceable in case of failure,
    - can be sourced from reliable and trust-worth suppliers that fulfil port authority regulations and requirements,
- Solution must assure redundant back-up system that can be maintained in case of failure,
- Installation must pass safety and security checks regarding its technical safety and cybersecurity before installation and go-live
- Assure that present technical and organizational solutions for shore power provision can be maintained as long as they are required by port regulations
- Solution must be easy to remove from the shore power infrastructure without much effort in dismantling and as such be minimum-invasive.

2.2.2 Functional Requirements

From a functional perspective, the solution

- shall enable digital and remote access, while still allowing for a manual and barrier-free access (via key).
- must guarantee access even in the event of a power or network failure. Skippers must be able to disconnect the cable even if the entire distribution box is without power.
- Meter readings shall be collected automatically and remotely.

In addition, the standards named above, specify that shore power solutions

- must provide operating instructions that are attached in a way that they are clearly legible for the users, including a display with language selection or a permanently attached sign in German, English, French, Dutch, Polish, Serbo-Croatian and Hungarian.

[3] Protected against dust and splashing of water.

- only be activated after authorization,
- activate and disconnect is possible at any time without the help of land-based personnel
- must enable billing in a suitable system if required,
- enable activation via one of the follow media: prepaid card, cash card, EC card, credit card, GPRS fleet cards, app / webpage.

2.2.3 Business Requirements

At the time of writing, 23 stations are already installed and in operation within the ports of Bremen and Bremerhaven.

- Existing facilities shall be maintained: Retrofitting solution with reasonable financial effort;
- Compatible with future stations → Process is important
- Installation shall be carried out with minimum efforts and minimally invasive.
- No additional maintenance effort.
- Network technology used for the shore power stations shall allow for integration of additional devices at berth (e.g., water meters, weather data sensors etc.).
- Technical standards must be adhered to, as well as legal and security requirements for smart submetering solutions.

3 IW-NET Shore Power Concept

3.1 Technical Concept

During the project and in the following course of this deliverable it was decided to follow an implementation using a low power, wide area network (LPWAN) and specifically the LoRaWAN networking protocol. However, the concept is not limited to that and can also be adapted and amended by using comparable IoT networking technologies such as NB-IoT. The overall system architecture that is proposed for the IW-NET shore power solution can represented on four layers (see Figure 2**Fehler! Verweisquelle konnte nicht gefunden werden.**)[4], which will be described in the following sections.

[4] With reference to (LoRa Alliance, n.d.)

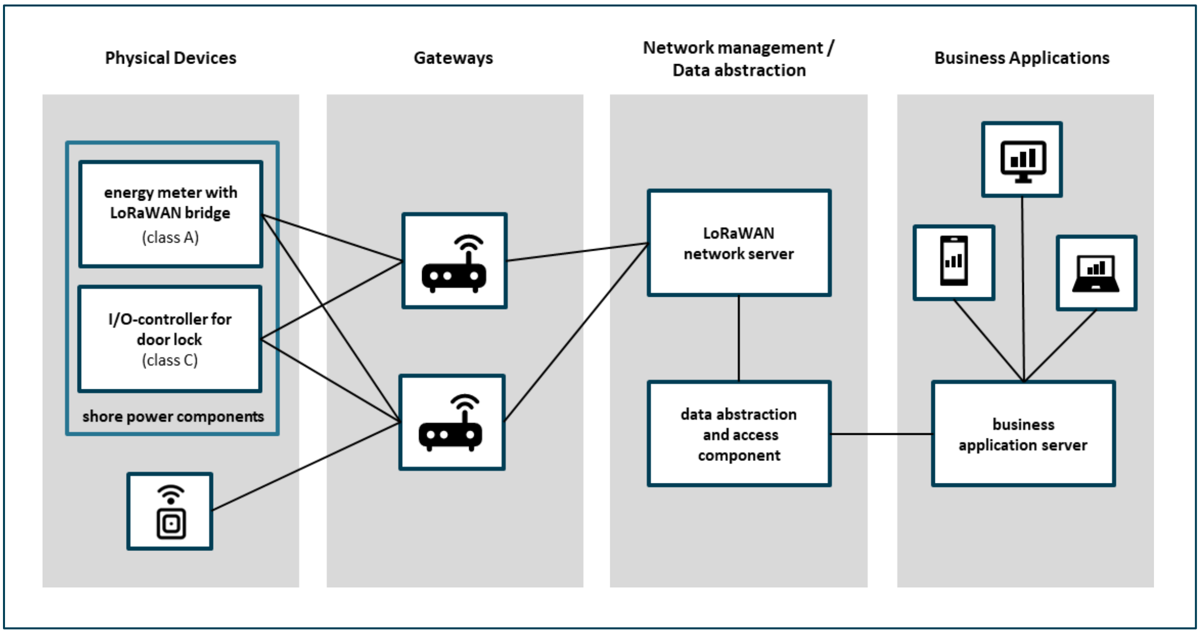


Figure 2: Generic Concept Overview

3.1.1 Physical Devices

The IW-NET retrofit solution consists of different sensors and actuators that are able to communicate via a wireless network and are thus referred to as IoT components. While sensors are used for collecting data, actuators are able to control movements or actions of physical components. The proposed solution makes use of the LoRa (short for Long-Range) radio frequency modulation technology. Deployed as a wide area network (LoRaWAN), the technology allows for a range from up to 3 km in dense suburban areas (Augustin, Yim, Clausen, & Townsley, 2016) to 15 km in rural areas (Adelantado, et al., 2017). Besides its high range, LoRaWAN networks pose very low energy consumption requirements to end devices connected to the network, enabling passive devices to have battery lives of up to 10 years (Semtech, 2019). The technology uses license-free frequency bands worldwide (863-870 MHz and 433 MHz in Europe). However, energy consumption as well as end device capabilities depend on the supported LoRaWAN operational classes.

In class "A", a device mostly operates in an inactive state called "sleep mode". It can send messages to the gateway (in the following referred to as an "uplink") in predefined intervals or triggered by an external event (e.g., change of observed variable). Therefore, it is not possible to send messages at any time which makes it unsuitable to operate as an actuator. In class "B", the end device will offer pre-scheduled windows in which "downlink" message can be received in addition to the class "A" windows. Class "C" devices often come with external power supply and can always receive downlink messages from the network. Therefore, they are suited to be operated as actuators.

To protect against unauthorized use of the shore power system, the outlets at the existing facilities are supposed to be installed inside a metal box and protected by a door with a key-lock.[5] As part of the IW-NET solution, the conventional mechanical lock is to be replaced by an electromagnetic locking mechanism that can be switched by a LoRaWAN I/O controller. Since downlinks need to be received by the controller at any time, it is required to work in Class C mode. In a closed state, the electromagnet is active to pull the door to the housing of the station. As soon as the controller receives a switching command, a relay is switched so that current is no longer applied to the electromagnet and the door can be opened for a predefined interval. After a predefined time period, the I/O controller switches

[5] See section 4.2

back again, thus closing the system as soon as the door touches the electromagnet. A spring mechanism ensures that the door is constantly pulled against the housing to prevent the door from being torn open by wind. Manual access, e.g., in the event of network outage or to allow for non-discriminatory access, a built-in key switch also connected to the electromagnetic lock also allows to deactivate the locking mechanism. To retrieve metering data from the station, three-phase electricity meters with a digital Modbus (RS485) interface will be installed and connected to a LoRaWAN bridge that allows to pull the required data from the electricity meter. As it is not necessary to constantly gather metering data, the bridge can be operated in Class A mode. Therefore, meter reading uplinks will be sent on predefined intervals.

As LoRaWAN is operated within an 868 MHz ISM band in Europe, each device and gateway needs to comply to duty-cycle limitations of 1%. Therefore, it is required to take a look at data rates and interval times of the selected LoRaWAN devices:

Message	Payload size	Transmission interval	Content
Uplink from modbus bridge	9 byte	15 min.	Meter number, meter kind, meter value
Uplink from IO controller	9 byte	10 min.	Status of the relays and I/O interfaces (e.g. used for door openeing and door sensor)
Downlink to IO controller	7 byte	on demand (< 10 per day)	Comand to open the door including the opening time
Uplink from temperature sens	11 byte	20 min.	Internal temperature, internal humadity, external humadity

All devices operate with spreading factor 7 and a bandwidth of 125 kHz. So, the transmitted data rates are far beyond the maximum data rate of 222 bytes. The airtime used for a 9-byte message every 10 minutes is 339.6 ms/h, which is far less than the allowed 1% duty cycle of 36 sec/h. However, for some faraway installations it may be useful to increase the spreading factor, which increases the stability of the transmission. A higher spreading factor increases the airtime used and lowers the data rate of the transmission. The airtime used for a 9-byte message every 10 minutes with the highest spreading factor 12 will take an airtime of 8.8968 sec/h. This would also be far beyond the maximum and increases the receiver sensitivity at -14 dBm (-123dBm to -137dBm) (The Things Network, 2023a), but lowers the data rate to a maximum of 51 bytes. Therefore, the spreading factor is a good parameter to play with in the real-world installations to support fast and reliable transmissions. It is acknowledged that downlinks send from the gateways to the IO-controllers for opening commands may be critical with regards to duty cycle limitations. It is expected to have around 25 shore power stations within the port network, each expectedly having a maximum of 10 requests for door openings a day. Given a maximum spreading factor of 9 (for RX2) and a payload size of 7 byte, this would mean a maximum of 194 msg/hour per gateway to stay within duty cycle limits[6]. However, depending on usage patterns of the shore power stations, the duty cycle may limit the capacity of the network and thus the number of downlink dependent devices.

3.1.2 Gateway

Within a LoRaWAN network, there is no direct association between a specific gateway and a sensor or actuator device. Instead, the gateways forward all received LoRaWAN modulated messages to a network server in the cloud, along with metadata such as a timestamp and signal strength information. Therefore, the LoRaWAN gateways are also referred to as packet forwarders. For this reason, an uplink message send by a device can be received by several gateways in reach, but finally processed in one central LoRaWAN server stack. Most gateways can either be connected to the internet either via a WiFi

[6] Please refer to (The Things Network, 2023b) for airtime calculations.

or Ethernet connection to or via cellular networks such as LTE or 5G. For additional security, gateways are may also establish VPN connections to be a part of a company's network, in which the relevant cloud services are hosted.

For the proposed system it is required to have at least one gateway in reach of the end devices at berth. However, gateway redundancy can reduce packet loss errors and thus improve reliability of the system. As described above, the reach of LoRaWAN networks can vary between a few and up to 15 kms. Against this background, the geospatial distribution as well as the environment (buildings, free spaces) plays a crucial role in gateway network design.

3.1.3 Network Management and Abstraction

This layer consists of a LoRaWAN Server Stack (which includes a LoRaWAN network server as well as a LoRaWAN application server) as well as an abstraction component. The LoRaWAN network server is responsible for the authentication and coordination of gateways (e.g., enforcing duty-cycle compliance), devices and messages within the network, while the LoRaWAN application server handles forwarding and encoding of uplink messages from the gateways, as well as decoding, scheduling/queuing and forwarding of downlink messages to the gateways. With regards to security, the LoRaWAN network provides end-to-end security using an encrypted message based on the AES128 approach.

The exchange of messages between the LoRaWAN server stack and the abstraction component can be done for example by using the MQTT protocol. The MQTT protocol enables a secure and seamless integration of these two components, so that incoming and outgoing messages can be processed without time loss. Due to the fact that the MQTT protocol is based on a publish/subscribe mechanism, it well suited for distributed systems.

Within the abstraction component, all messages received will be unpacked transformed and stored within a database. It also provides the required means to enable access to end-user applications through machine-readable web interfaces.

3.1.4 Business Application

The business application layer incorporates all applications that are intended to access shore power data or apply certain business logics to the use of it, e.g., authentication.

In the context of the project, the IW-NET web application will serve as the business application that integrates the solution into workflows for port users and infrastructure managers. With this application, port users will be able to open the metal box by means of any mobile device or laptop that has an internet connection. Within the web application, authorization is granted via the registration of a port call by the port user and a corresponding berth assignment by the competent port authority. Irrespective of this, port infrastructure operator's personnel receive access via a dedicated interface within the application software.[7]

3.2 IW-NET Shore Power Process

A detailed mapping of the current shore power process in AS2[8] has been used as a baseline for the IW-NET shore power solution. The main rationale for the process redesign was to minimize efforts required by the port user as well as by the port authority. For this reason, it has been decided to link the authorization for the use of shore power to the berth assignment by the traffic management

[7] A detailed description of the IW-NET web application is given in IW-NET deliverables D2.3 (confidential) and D2.5.

[8] See D4.3

department, while monitoring of power consumption is automized and requires no manual intervention. The technological foundation required to implement this process is the implementation of the remote-control capabilities as described in the preceding chapters, as well as a digital communications link between port users and port authority as described in D2.3/D2.5. A simplified visualization of the redesigned process is shown in Figure 3.[9]

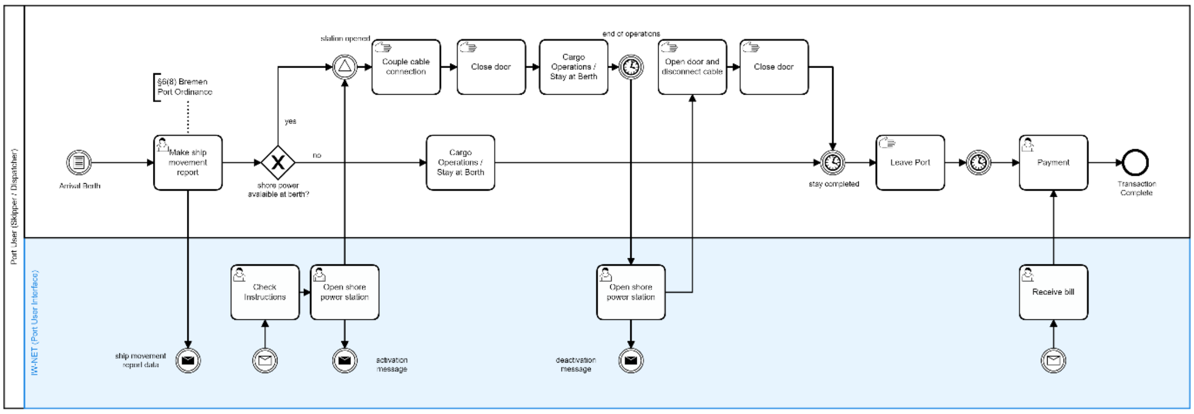
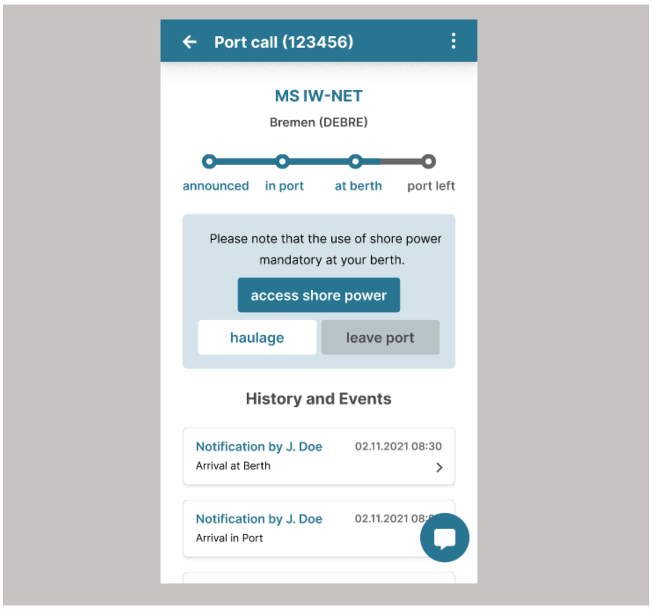


Figure 3: IW-NET Shore Power Process (Port User Perspective - simplified)

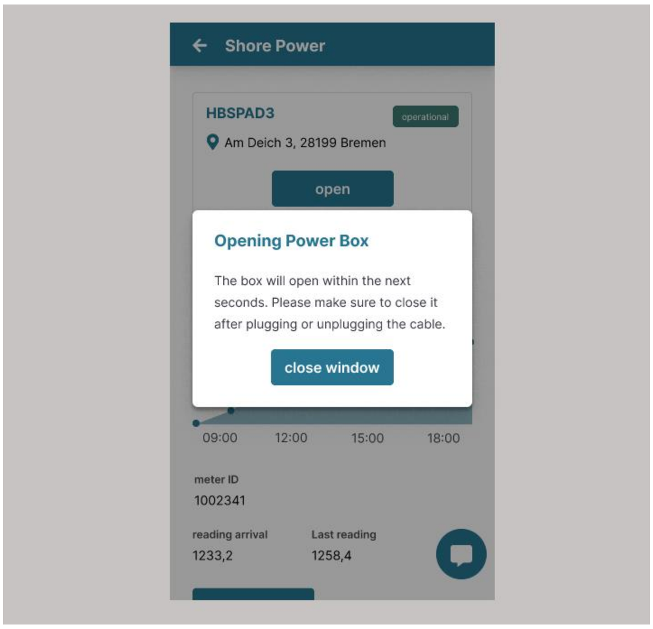
From the perspective of port users, the IW-NET shore power process includes the following steps:

1. Traffic Manager assigns berth to specific port call upon port arrival message.
2. Skipper/onboard personnel acknowledges arrival at berth via IW-NET web interface using a mobile device such as a smartphone, tablet or laptop: Due to the berth assignment carried out in step 1, authorization to open the power box is granted.

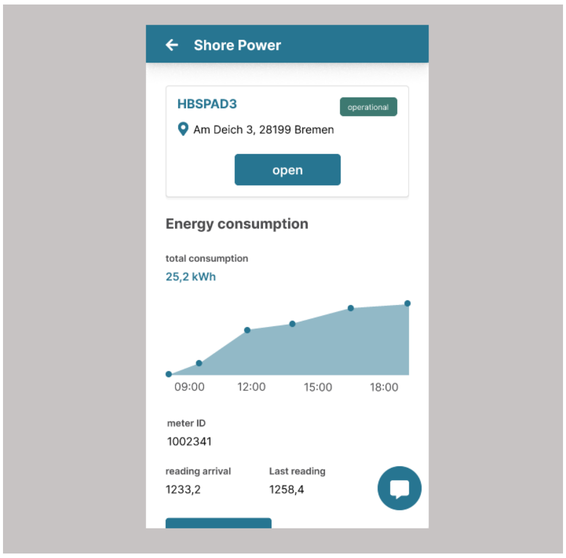


3. Skipper/onboard personnel is able to open the power box using the web interface. Door sensors will notify door opening status. Cables can now be plugged into required outlets.

[9] Full version shown in appendix



4. If required, skipper/onboard personnel will be able to consult technical instructions given by the IW-NET web application.
5. During the stay or before leaving the respective berth, skipper/onboard personnel will always be able to open power box using their credentials on the web interface to disconnect the cables. Also, the user will always be able to monitor current energy consumption.

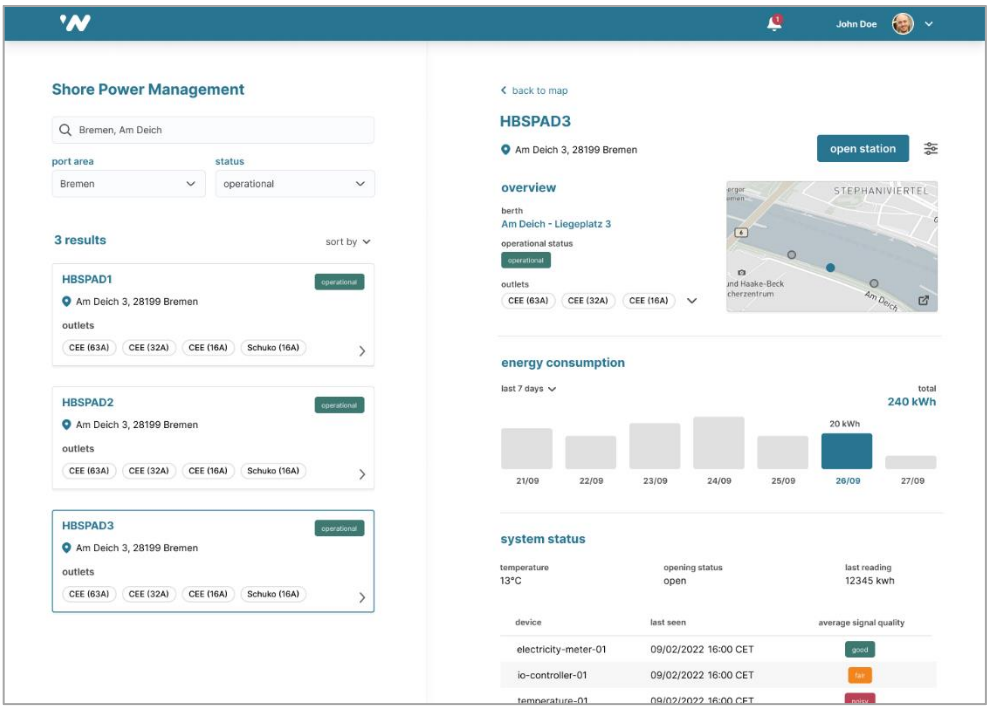


6. Skipper/onboard personnel announce leaving of berth or port. The IW-NET application will now be able to calculate a final consumption report per berth stay based on the actual time of arrival (ATA) and actual time of departure (ATD).

As all stations will still be equipped with a key-based lock, the legacy process can still be used as backup in case of network or system outage.

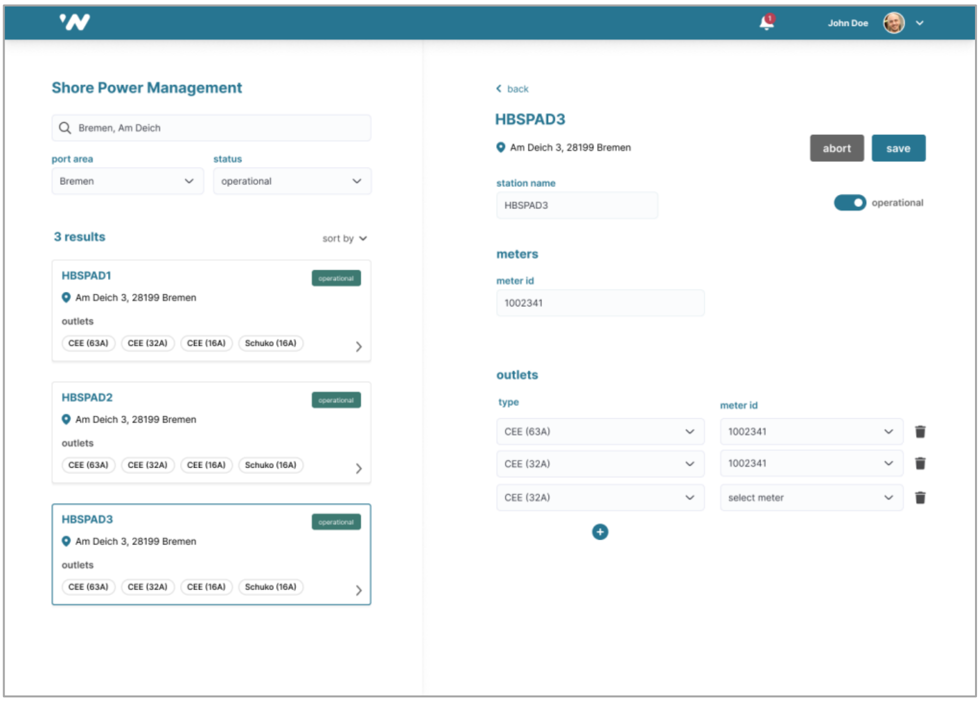
Besides the redesigned process of using shore power, the solution provides novel procedures to traffic and infrastructure managers in order to monitor and manage the shore power solution via the IW-NET web application. First of all, it is possible to gather real-time status information[10] on specific stations, which includes

- opening status
- last seen
- average signal strength and uplink reliability
- historical and current meter readings



Furthermore, it is possible to change the operational status of a shore power station e.g., in case of maintenance or outage, which will automatically prevent all users from using the respective station. Infrastructure managers may also add or change master data (e.g., name, outlets) of a specific station. In addition, opening every station remotely, will be possible as well. This may be required, if a skipper does not possess an internet-ready device or if non-regular users (e.g., in case of street festivals etc.) need to access the stations.

[10] Real-time in this context relates to the update interval of the LoRa devices (see chapter 3.1.1.1)



4 IW-NET Shore Power Implementation

4.1 Functional Shore Power Demonstrator

During the development process, a functional prototype as well a “near-series” prototype has been developed. The functional prototype differs from a near-series prototype in that the IoT components were not installed on a real shore power facility and for development and testing purposes only. In addition, an AC instead of three-phase electricity was used, so that testing and demonstration is easily possible with conventional household electricity. Construction and testing of the functional demonstrator have taken place from 06/2021 to 12/2022.

The functional demonstrator includes a non-scale plastic housing with DIN rails, which is mounted on an aluminium profile stand. Due to its weight of less than 20kg, it is fully portable. The opening mechanism of the housing has been realized using a 12V electrical door magnet which is placed opposite to a steel plate. To illustrate the backup-process, that is required to use the station in case of network outage or other failure, a door switch has been installed as well.

Figure 4: IW-NET Functional Shore Power Demonstrator (src: Institute of Shipping Economics and Logistics)

The demonstrator station's energy supply is realized using a CEE 7/4 plug and 230V/16A AC, while two CEE 7/3 sockets were installed within the housing and connected to a DZG AC meter (WH4013) to mock energy consumption in a real shore power station. This allows to flexibly test and demonstrate the solution with household electricity. The AC meter used for the demonstrator comes with a Modbus interface, which can also be found on comparable three-phase meters.

The IoT-components where selected to match the required requirements as set out in 2.2. In specific, a DZG Modbus bridge (LoRaMOD-R4.G2) as well as a Dragino I/O controller (LT-22222-L-EU868) have been mounted on DIN rails within the housing to be able to remotely control and monitor the station. The Modbus bridge was connected to the meter and an external antenna, and allows to capture and regularly transmit the meter's readings. The I/O controller, which was used with a small SMA antenna allows to control a relay which is further connected to the electrical magnet. To capture door openings a door sensor connected to the I/O controller was installed as well.

4.2 Near-Series Demonstrator (AS2)

4.2.1 Retrofit design

Due to satisfying performance evaluation in the functional demonstrations, the general design and selection of components was adopted for the near-series demonstrations in WP2. Few adjustments had to be made:

- As real stations are operated using three-phase current, another meter from the DZG product family (DVH4013) has been installed in the near-series demonstrator.
- Due to risk of vandalism, a stronger magnet has been selected.
- Additional antennas have been placed outside the housing to allow for higher signal strength.

Further adjustments had to be made in order to fulfil IP requirements. The retrofit-solution in the near field demonstration has been placed into a small aluminium box that is mounted next to the existing station and wired using cable conduits.

Figure 5: Installation of IW-NET component at existing shore power station (src: bremenports GmbH & Co. KG)

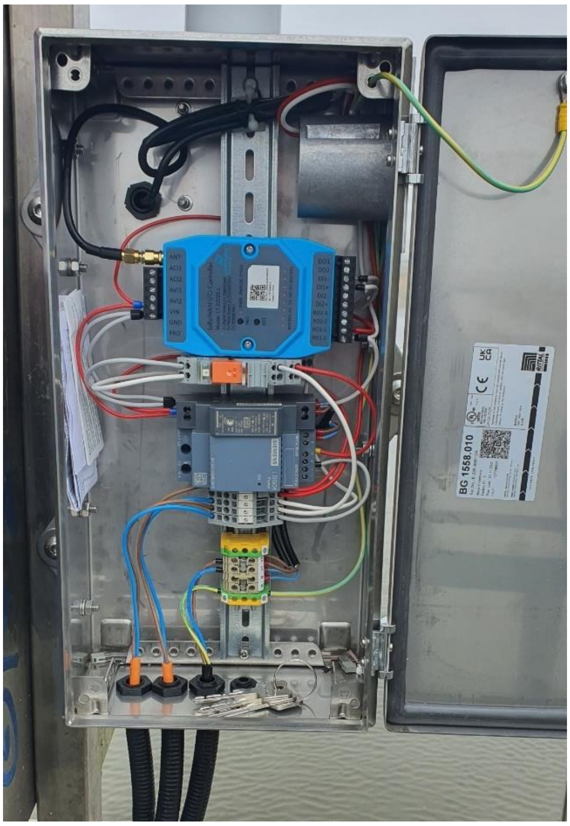


Figure 6: Closeup of IW-NET plugin (src: bremenports GmbH & Co. KG)

Figure 7: Magnetic opening mechanism within existing shore power station (src: bremenports GmbH & Co. KG)

4.2.2 Gateway

The gateway layer makes use of mass-produced LoRaWAN gateways that were configured using a 4G/LTE link to the internet and establish VPN connections to the company's network. A Milesight UG67-L04EU-868M and a RAK WisGate Edge Pro cellular gateway[11] which are expected to meet the technical requirements for outside testing (e.g., IP67 protection) have been selected and used to setup the testing network. In a first testing phase, the Milesight gateway has been placed in different locations within the AS2 environment to evaluate the coverage of one gateway in consideration of surrounding buildings and installation heights (for examples see Figure 9 and Figure 11). Based on these results, a specific location has been selected and the gateway installed permanently (fixed mounting and energy supply). In order to increase the coverage of the network, the second gateway which was temporarily placed on several sights during field testing are expected to be installed permanently for the AS2 evaluation.

[11] Please refer to the annex A2 for further technical specifications.

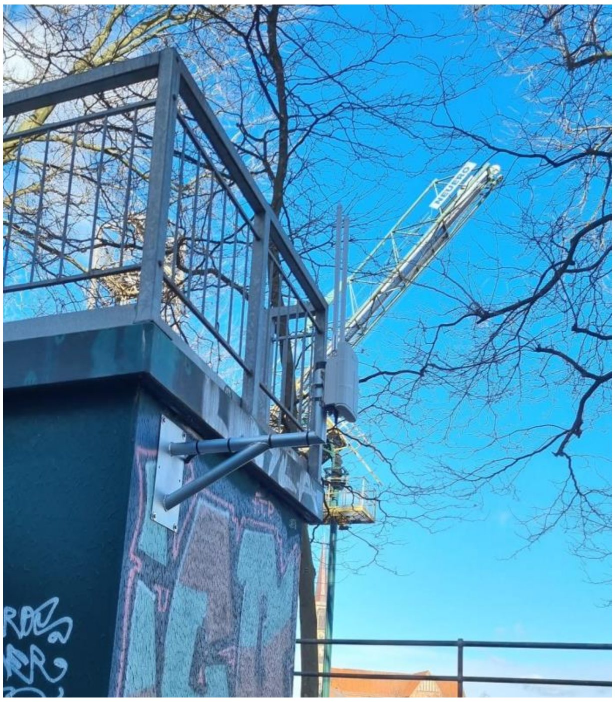


Figure 8: Gateway installed at bremenports facilities within Bremen (src: bremenports GmbH & Co. KG)

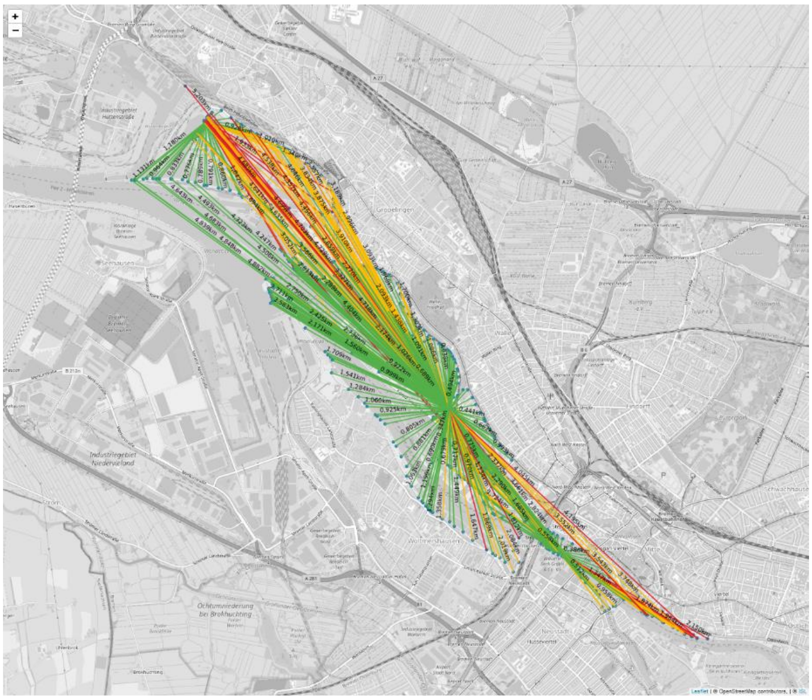


Figure 9: Visualization of signal strengths to identify suitable gateway locations (good: green; average: yellow; poor: red)

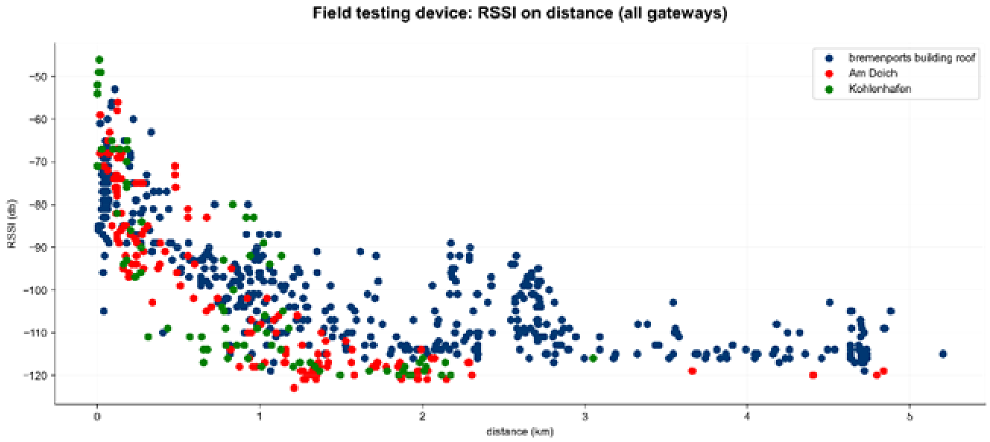


Figure 10: Visualization of signal strengths during testing

4.2.3 Network Management and Abstraction

The network management component, was implemented using a self-hosted LoRaWAN server stack "Things Stack" which is provided as open source by the The Things Industries. While it would be possible to use a public LoRaWAN network, the decision to setup a private LoRaWAN network has been made to be less dependent to external suppliers, as thus gain full control over the network and the respective data.

As LoRaWAN is optimized to operate on very low energy requirements, the data captured by LoRa devices is encoded to a binary payload upon data transmission. Therefore, decoding of messages received and encoding of messages to be send needs to be done on the LoRaWAN application server level. This is done using payload converters that in the case of the Things Stack are written in JavaScript language. These decoders have been created based on the product specifications of the LoRaWAN devices (see 3.1.1).

The Things Network offers an MQTT interface which is consumed by the IW-NET abstraction component. This component was realized using the Quarkus framework[12] as a microservice and is responsible for data storage within a PostgreSQL database as well as sending downlink requests to the network server and thus the LoRaWAN network.

The interface between the IW-NET shore power solution and the business applications is realized using two microservices, that each provide a REST-API. While the "Port User"-API provides the functionalities to access stations and consume meter reading data as well as station metadata, the "Administration"-API allows to add, alter or delete the station configuration data. While it would have been possible to combine all functionalities within one web API interface, the decision to technically separate both APIs has been made to increase maintainability as well as the security of the system.

[12] https://quarkus.io/

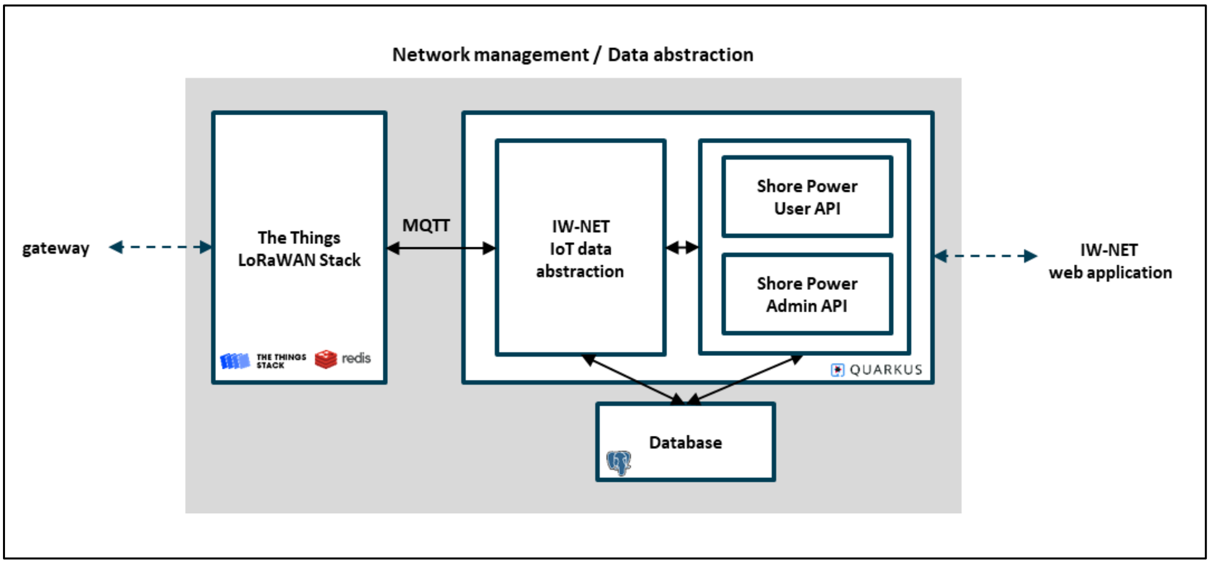


Figure 11: Implementation of network management and data abstraction

4.3 Risk Assessment

An assessment of risks was carried out to emphasize areas of the proposed solution that need attention and mitigation during its deployment. The following risks have been identified and evaluated:

Risk	Evaluation	Mitigation
Network / System Outage	In general, the provision of shore power for conventionally powered inland vessels is primarily an environmental necessity. The risk of impairments on nautical and logistical processes can therefore be considered as being rather low. However, the service quality of shore power strongly influences the perceived port service quality by port users and can be subject to cybersecurity threats as part of critical and digital port infrastructure.	A key-based backup procedure will be installed within the solution to allow for access even in case of complete network failure.
Data Theft / Manipulation	Besides impairments of the system, the theft or manipulation of data may be a potential cybersecurity threat. The main data that is transmitted within the system and thus can be intercepted or manipulated are the meter readings. However, given that the interpretation of data (e.g., linking it to specific port calls) will be done by the respective business application, there is no additional risk associated to collecting these meter readings remotely. Furthermore, attackers could try to get unauthorized access to shore power stations. Assuming that this would be possible, the effort to do so digitally would probably exceed to do the same	The communication between the physical device layer and the network server is secured via the LoRaWAN end-to-end encryption mechanism (see 3.1.3). Furthermore, communications between components as well as between components and external systems are protected using API-keys and firewall or proxy configurations.

	physically (breaking the locking mechanism).	
Duty-Cycle Limitations	Depending on the usage patterns and the number of shore power stations as well as available gateways integrated within the network, duty cycle limitations may reduce the availability of the stations and thus the system's performance (see 3.1.1).	Assumptions on real usage patterns to be tested within AS2 field tests. Readiness for integration of other network solutions (e.g., NB-IoT).

4.4 Business Considerations

Inland vessels berthing in the Ports of Bremen and Bremerhaven are legally required to link up to onshore power supply (OPS) to obtain electrical energy. OPS is defined as a shore-based system for providing electrical energy to ships in port for them to avoid having to run on-board generators.

On the one hand, there is a public interest in reducing emissions from ships in ports; on the other generation of electrical energy has been a matter of private interest on board of vessels. With the introduction of OPS both interests overlap, and with it, business considerations emerge.

Providing an OPS requires investments not only into electrants on jetties and at berths, but also into cabling/switch gear infrastructure linking supply points to the public grid. In North-Western ports, the provision, operation and maintenance of marine-related infrastructure, such as quay-walls, locks, port roads and railyards, and land securement are public services.

Provision of electrical energy to vessels while at berth adds a new element to the portfolio of vessel-related services, such as pilotage, towing, line handling (for sea-going vessels) or waste disposal (for all vessels) in ports. In European ports, public and private organisations provide those services, either purely market-driven and at the sole risks of the purveyor, or as a concessioned entity or as a public service of general interest. As such, OPS is at the fringe of public infrastructure provision in ports. With this overlap, the question of how to provide and (commercially) operate an OPS emerges.

bremenports as public landlord, and thus responsible for providing onshore power, assumes that the difference between procurement and sales price per unit of electricity (the "margin") is too small to go without public contributions. The margin is considered insufficient for private, i.e., profit-seeking, entities to plan, construct, finance and operate an OPS entirely based on selling the energy.

Should this assumption hold true, an OPS system was supposed to be an entirely public affair and the task at hand would be limited to estimating the size of a public contribution towards an OPS. However, implicit to this assumption is the notion that there is a margin when delivering electrical energy to ships, whatever its size. Thus, we can argue for exploring options to combine public and private interests in OPS provision, and within those options, to consider market-based elements.

At the moment, in the Ports of Bremen, the "costs" for using shore-side electrical energy are bundled into the harbour fees of using a berth. Unbundling this opens up opportunities to bring in private parties to provide an OPS that refinance themselves by means of selling electrical energy to ships driven by the monopolistic stipulation in the port´s by-laws to connect to an OPS. Nevertheless, there might be a market-risk for the private partner to bear in terms of future vessels calls times the expected energy consumption per call times a price per unit of energy sold in this way.

The resulting options of economic use cases within AS2 will be identified, described and analysed in IW-NET D4.3.

5 Conclusion and Outlook

Providing inland vessels with shore power at berths often requires extensive investments on the side of infrastructure providers as well as the acceptance within the inland navigation sector. The solution proposed within the IW-NET project and which was described within this deliverable addresses these impediments by offering a comparatively cost-effective way to upgrade and monitor existing stations and by integrating the use of shower power into a digital and user-centric port call process.

While the solution has been inspired by the existing conditions within IW-NET application scenario 2, its component-based architecture makes it adaptable to other comparable settings in Europe. As an example, the integration of the IW-NET web application is not necessarily required, as the REST-APIs could also be integrated by other solutions. This makes it also possible to operate any upgraded station in environments with less sophisticated communications/berth allocation processes as it is the case for berths along the waterway or at lock facilities. Also, it would be possible to implement the physical device and gateway layer with other wireless communications technologies such as NB-IoT.

In the future, the approach of using LPWAN within port environments offers favourable conditions for other infrastructure applications beyond the scope of shower power. Use cases that can amend the IW-NET shore power solutions include the installation of water meters, temperature and water level sensors, distance sensors to physically monitor berth occupation or leakage detection.

Beyond the scope of the project, the deployment of the solution within a real port environment may be used for corridor-wide harmonization of the shore power process. As proposed by Wisselmann & Kempmann, the experience should thus be taken up by public policy (Wisselmann & Kempmann, 2023).

6 Appendix

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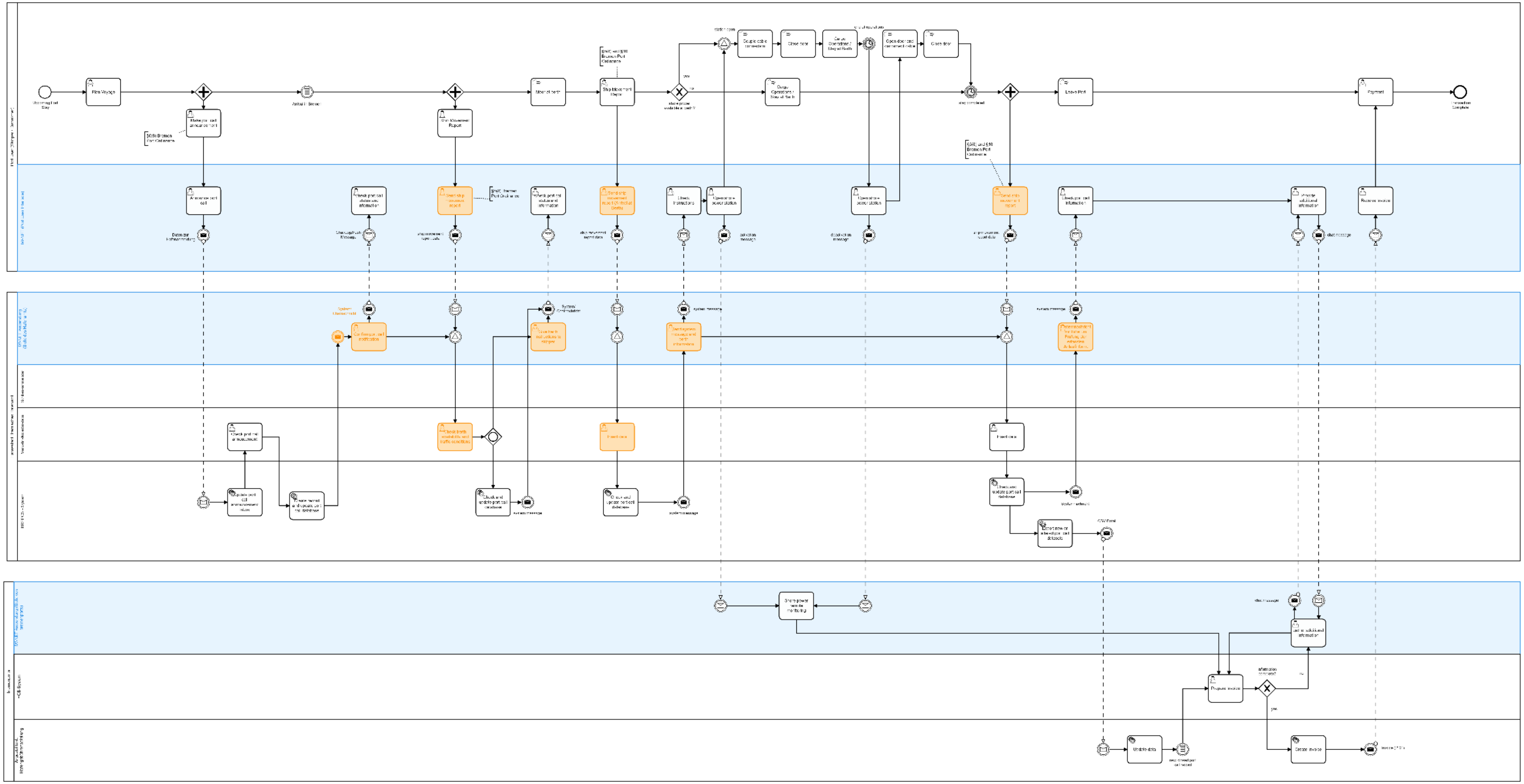
Annex

A1: Process Diagram



A2: Gateway specifications

	Milesight UG67-L04EU-868M Cellular	**RAK WisGate Edge Pro RAK7289, 16 channels**
LoRa-Chip	Semtech SX1302	Semtech SX1303
Channels	8	16
CPU	Quad-core 1.5 GHz, 64-bit ARM Cortex-A53	Single-core 580MHz, 32-bit MediaTek MT7628
Memory	512 MB DDR4 RAM	128 MB DDR2 RAM
Flash	8 GB eMMC	
Housing	IP67 industrial-grade enclosure	IP67 industrial-grade enclosure