



# Key Performance Indicators for measuring energy efficiency in port terminals



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# Agenda

1. Rationale of the study
2. Theoretical framework & research objectives
3. Method
4. Results & findings
5. Implications for research/policy

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# Background



- The **port industry** as an **energy-intensive sector**, generating negative externalities and environmental impacts in several areas, e.g., air emissions, water emissions, etc. (Bailey and Solomon, 2004; Dinwoodie et al., 2012).
  - magnitude of highly impacting business processes/activities embedded in port spaces
  - variety of economic actors located within/around port boundaries.
- These arguments are urging for the adoption of **innovative green strategies** for the reduction of energy consumptions, making energy management more efficient (Acciaro, 2015).
- The increasing number of academic contributions on this issue and the implementation of energy policies and funding programmes for pursuing energy efficiency targets, demonstrate the attention to the mitigation of the environmental impact at EU level.

# Anecdotal evidence



## Energy efficiency

One of the biggest costs for industry in the port is energy consumption. For this reason, measures are always being sought to save on this use. By optimising processes and implementing new techniques, such as improved heat integration, insulation and process optimisation, an additional 20% can be saved. This programme is led by Deltalinqs, the representative of the business community in the port.

## Sustainable energy

The port of Rotterdam is an attractive location for sustainable energy production such as solar energy, wind energy and energy production from biomass. The port offers logistical advantages for the supply of raw materials. Furthermore, space has been reserved for wind turbines and solar panels. The Municipality of Rotterdam, the Dutch central government, the province of South Holland and the Port of Rotterdam Authority also have a strong focus on sustainability and they stimulate sustainable initiatives.

1. Rationale of the study

## Renewable energy

Sustainable or renewable energy is crucial in any vision of the future. Whether it is for direct application as electricity or heat, or sustainably produced hydrogen as a production raw material, the demand for renewable energy is growing steadily. This is why we are working on sustainable energy generation in the port and outside the port.

There are currently 200 megawatts of wind turbines in the port of Rotterdam area. By 2020, we want to add at least 150 megawatts of new wind power. There is also the ambition to install solar panels on as many roofs as possible and a pilot project for ultra-deep geothermal energy is in preparation. The Port Authority is actively involved in the development of the NorthSea Wind Power Hub: large-scale generation of offshore wind energy with the possibility of converting it directly at sea into hydrogen, for example.

## Energy from biomass

Co-firing biomass in power stations is an important way to reduce CO<sub>2</sub> emissions in energy generation. That is why co-firing forms a major part of the Dutch Energy Agreement and is stimulated by subsidies. The new coal-fired power stations of Engie (formerly GdF Suez) and Uniper (formerly EON) on the Maasvlakte are both capable of co-firing 20 to 30 per cent biomass. The biomass co-fired in coal-fired power stations usually consists of imported wood chips, but residual materials, for example from the biobased chemical industry, can also play a part. The AVR biomass power station (BEC) in Rozenburg runs entirely on residual wood.

## Wind energy

The port of Rotterdam is an attractive location for wind farms. With the North Sea just outside, the wind blows almost all the time. The Port of Rotterdam Authority, the Municipality of Rotterdam and the Dutch government have a strong focus on sustainable energy generation and wind energy. Currently, wind turbine capacity in the port area generates 200 megawatt (MW). In its Port Vision, the Port of Rotterdam Authority has committed itself to 300 MW installed wind energy in the port of Rotterdam by 2020.



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# Port Energy Management

- Acciaro, M., Ghiara, H., and Cusano, M. I. (2014). Energy management in seaports: A new role for port authorities. *Energy Policy*, 71, 4-12.
- Parise, G., Parise, L., Martirano, L., Chavdarian, P. B., Su, C. L., & Ferrante, A. (2015). Wise port and business energy management: port facilities, electrical power distribution. *IEEE Transactions on Industry Applications*, 52(1), 18-24.
- Boile, M., Theofanis, S., Sdoukopoulos, E., & Plytas, N. (2016). Developing a port energy management plan: Issues, challenges, and prospects. *Transportation Research Record*, 2549(1), 19-28.
- Hentschel, M., Ketter, W., & Collins, J. (2018). Renewable energy cooperatives: Facilitating the energy transition at the Port of Rotterdam. *Energy Policy*, 121, 61-69.

## Other authors:

- include energy management of ports into broader **actions** taking place at a **wider territorial scale** (e.g., municipality, region, etc.)
- deal with energy management within the «**green deal**» of PAs
- focus on **technological innovations** improving energy efficiency (e.g., BPR, monitoring systems, bi-generation system, etc.), reducing emissions (light bulbs, insulation, electric engines) and producing renewable energy (e.g., solar cells, wind/wave/tide energy, etc.).

# Literature gap and research objective

- **Theoretical models and quantitative methods** for investigating **energy consumptions** in ports are still underdeveloped.
- **Empirical dataset regarding port energy consumption** are still lacking because of the scarce diffusion of culture in energy management in Port Authorities and private terminal operators.
- This topic needs an **interdisciplinary approach** (economic and engineering perspectives)



- **Research objective:** to develop an “ad-hoc” **conceptual framework for estimating energy consumption** which originates in different typologies of port facilities

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# Method (1/2)



- Different categories of port terminal and facilities are included in the study:
  - ✓ **General cargo terminals** (multipurpose vs. container);
  - ✓ **Dry bulk terminals**;
  - ✓ **Liquid bulk terminals**;
  - ✓ **Shipyards**;
  - ✓ **Ferry and cruise terminals**;
  - ✓ **Marinas**;
  - ✓ **Hybrid ro-ro and passenger terminals**;
  - ✓ **Other port areas**.
- For each typology of energy-consuming terminals, alternative customized **Key Performance Indicators (KPIs)** capable to identify standard (average) energy consumption rates for each terminal category are proposed and discussed.
- The methodology adopted considers both thermal and equivalent electrical energy consumptions.

# Method (2/2)



- The **proposed KPIs** calculate **energy consumptions** (kWh) based on relevant variables such as:
  - **spatial areas** (e.g., sqm of terminal areas) dedicated to port activities;
  - **traffic flows** (e.g., handled tons, passengers, cruisers);
  - **process outcomes** (e.g., steel coils production);
  - **capacity** (e.g., metres of berths).
- The **selected KPIs** are operationalized mostly considering energy consumption rates referred to spatial areas or to (cargo/passenger) traffic flows.
- The KPIs are calculated from the effective energy consumptions related to **43 terminals** located in several Italian ports, as the manuscript benefits from data and information gathered by the Authors when collaborating to various European projects focused on port energy, such as **TDI RETE-GNL** and **SIGNAL** (INTERREG ITA-FRA Maritime 1420).

# Port energy consumption: standard KPIs included in the conceptual framework



Terminal category	Relevant KPIs		Selected KPIs		Sample (n. sample concessionaires)	KPIs_ Equivalent Electrical consumption		KPIs_ Thermal consumption	
	Electrical consumption	Thermal consumption	Electrical consumption	Thermal consumption		kWh/mq	kWh/Ton_eqv	kWh/mq	kWh/Ton_eqv
General Cargo_ Mutipurpose	kWh/Ton_eqv	kWh/Ton_eqv; kWh/sqm	kWh/Ton_eqv	kWh/Ton_eqv	5	20,12	<b>1,01</b>	34,85	<b>1,91</b>
General Cargo_ Container	kWh/TEUs; kWh/Ton_eqv	kWh/TEUs; kWh/Ton_eqv; kWh/sqm	kWh/Ton_eqv	kWh/Ton_eqv	4	71,99	<b>3,27</b>	55,75	<b>2,53</b>
Dry bulk terminals	kWh/Ton_eqv	kWh/Ton_eqv; kWh/sqm	kWh/Ton_eqv	kWh/Ton_eqv	5	44,87	<b>4,07</b>	26,92	<b>2,44</b>
Liquid buk terminals	kWh/Ton_eqv	kWh/Ton_eqv; kWh/sqm	kWh/Ton_eqv	kWh/Ton_eqv	7	58,74	<b>6,73</b>	36,31	<b>4,21</b>
Shipyards	kWh/Ton_eqv; kWh/sqm; kWh/Ton of steel sheet processed	kWh/Ton; kWh/sqm; kWh/Ton of steel sheet processed	kWh/sqm (areas in concession)	kWh/sqm (areas in concession)	11	<b>180,65</b>	-	<b>93,67</b>	-
Ferry/cruise terminals	kWh/covered sqm; kWh/uncovered sqm; kWh/total sqm	kWh/sqm; kWh/m <sup>3</sup>	kWh/sqm (areas in concession)	kWh/sqm (areas in concession)	1	<b>38,65</b>	-	<b>6,94</b>	-
Marinas	kWh/sqm in concession; kWh/sqm berths and water basin; kWh/occupied berth	kWh/sqm in concession; kWh/smq berths and water basin; kWh/occupied berth	kWh/sqm (berths and water basin)	kWh/sqm (berths and water basin)	2	<b>8,97</b>	-	-	-
Other port facilities	kWh/sqm	kWh/sqm	kWh/sqm (areas in concession)	kWh/sqm (areas in concession)	6	<b>16,19</b>	-	<b>13,32</b>	-

# Hybrid ro-ro and passenger terminals: weighted KPIs



- Given their specificities, **hybrid ro-ro and passenger terminals** require an ad-hoc weighing of the different factors composing the associated KPIs
- The weighted KPI includes 4 sub-KPIs:
  - ✓ Passenger/cruiser flow
  - ✓ Cargo handling
  - ✓ Port areas in concession
  - ✓ lightingtower

Component	Equivalent Electrical consumption				Thermal consumption			
	KPI	Description	Weight on the final KPI (%)	Estimated KPIs	KPI	Description	Weight on the final KPI (%)	Estimated KPIs
Energy consumption related to passenger and cruiser flow	kWh/flux_p+c	kWh per passenger/cruiser	25,00%	3,70	kWh/flux_p+c	kWh per passenger/cruiser	33,34%	0,66
Energy consumption originating from cargo handling	kWh/Ton_eqv	kWh per equivalent ton of cargo handled	25,00%	1,04	kWh/Ton_eqv	kWh per equivalent ton of cargo handled	33,33%	2,12
Energy consumption related to port areas in concession	kWh/sqm	kWh per mq in concession	25,00%	39,07	kWh/sqm	kWh per mq in concession	33,33%	7,01
Energy consumption related to lightingtower	kWh/lightingtower	kWh per number of lightingtower	25,00%	10130	-	-	-	-

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# Empirical testing

- **Standard KPIs** have been used for estimating the overall energy consumption in several terminal/facilities located in **Italian** and **French ports**, for which real energy consumption data was not available.
- The sample ports constitute a heterogenous and highly representative set of large vs. small ports as well as cargo diversified vs. specialized logistic nodes (Genoa, Leghorn, Portoferraio, Oristano, Cagliari, Bastia, Toulon and Nice).

## *Sampled ports, terminals and concessionaries*

Port	General cargo_multiple purpose terminals	General cargo_container terminals	Dry bulk terminals	Liquid bulk terminals	Shipyards	Ferry/cruise terminals	Marinas	Hybrid ro-ro & passenger terminals	Other port facilities	Total
Leghorn	2	5	7	5	7	1	6	2	1	36
Portoferraio	0	0	0	0	4	0	4	1	2	11
Oristano	1	0	4	1	1	0	1	0	11	19
Cagliari	1	1	1	1	3	1	3	0	3	14
Bastia	0	0	0	0	1	0	2	1	0	4
Toulon	0	0	0	0	7	0	4	1	4	16
Nice	0	0	0	0	1	0	2	2	1	6
Genoa	4	2	2	9	11	1	7	0	1	37
<b>Total</b>	<b>8</b>	<b>8</b>	<b>14</b>	<b>16</b>	<b>35</b>	<b>3</b>	<b>29</b>	<b>7</b>	<b>23</b>	<b>143</b>

*Source: Authors' own elaboration on TDI RETE-GNL and SIGNAL INTTERREG ITA-FRA Maritime 14-20 Projects*

# Data for estimating port energy consumptions

*The extension of the sample port areas: breakdown per port and terminal typology*



Port	A General cargo_multipurpose terminals	B General_cargo_container terminals	C Dry bulk terminals	D Liquid buk terminals	E Total terminals area (A+B+C+D)	F Passenger/ferry terminals and hybrid ro-ro and passenger terminales	G Marinas (water basin included)	H Shipyards	I Other port facilities	L Total sampe areas (E+F+G+H+I)
Leghorn	160.881	562.559	150.009	69.783	943.232	144.236	285.871	31.497	117.605	1.522.441
Portoferraio	0	0	0	0	0	25.000	184.078	201.413	12.639	423.130
Oristano	205.000	0	438.812	189.504	833.316	0	80.866	9.268	111.692	1.035.142
Cagliari	134.389	400.000	9.302	6.498	550.189	230.000	409.124	18.870	896.040	2.104.223
Bastia	0	0	0	0	0	100.000	60.983	4.034	1.614	166.631
Toulon	0	0	0	0	0	55.000	216.383	56.995	183.283	511.661
Nice	0	0	0	0	0	43.000	85.728	2.324	52.899	183.951
Genoa	738.947	1.124.463	138.199	305.593	2.307.202	298.000	1.496.689	398.671	910.362	5.410.924
<b>Total</b>	<b>1.239.217</b>	<b>2.087.022</b>	<b>736.322</b>	<b>571.378</b>	<b>4.633.939</b>	<b>895.236</b>	<b>2.819.722</b>	<b>723.072</b>	<b>2.286.134</b>	<b>11.358.102</b>

*Cargo and passenger throughput: breakdown per port and type of traffic flows*

Port	Traffic flows						
	General Cargo_Container	Ro-Ro	Other general cargoes	Dry bulk	Liquid bulk	Passengers	Cruisers
<i>(measur unit)</i>	<i>Ton/year</i>	<i>Ton/year</i>	<i>Ton/year</i>	<i>Ton/year</i>	<i>Ton/year</i>	<i>Passengers/year</i>	<i>Cruisers/year</i>
Leghorn	9.196.116	12.413.062	2.012.242	831.615	8.362.816	2.475.906	807.935
Portoferraio	0	2.825.337	0	0	0	3.061.798	0
Oristano	0	180	0	1.118.743	226.173	0	0
Cagliari	8.452.226	3.974.366	48.476	801.920	26.743.264	580.730	258.066
Bastia	0	2.081.485	0	0	0	2 142 850	35 854
Toulon	0	525.000	408.000	176.000	0	1.370.000	239.023
Nice	0	713.000	0	0	0	1.158.709	695.000
Genoa	22.377.403	8.594.711	623.524	3.651.167	14.582.780	2.093.064	1.017.368
<b>Total</b>	<b>40.025.745</b>	<b>31.127.141</b>	<b>3.092.242</b>	<b>6.579.445</b>	<b>49.915.033</b>	<b>10.740.207</b>	<b>3.017.392</b>

Source: Authors' own elaboration on TDI RETE-GNL and SIGNAL INTTERREG ITA-FRA Maritime 14-20 Projects

# Estimated energy consumption in the sample ports

Port	Type of energy	[kWh/year - equivalent energy]	[kWh/year - electrical energy]	Sum of equivalent energies	Electrical + Thermal energy consumption
·Leghorn	Equivalent electrical energy	138.027.778,38	63.492.778,06	239.133.350,95	164.598.350,63
	Thermal energy	101.105.572,57			
·Portoferraio	Equivalent electrical energy	29.143.459,27	13.405.991,26	42.731.221,98	26.993.753,98
	Thermal energy	13.587.762,72			
·Oristano	Equivalent electrical energy	12.509.710,82	5.754.466,98	19.689.353,93	12.934.110,09
	Thermal energy	7.179.643,12			
·Cagliari	Equivalent electrical energy	252.188.253,33	116.006.596,53	414.354.502,08	278.172.845,28
	Thermal energy	162.166.248,75			
·Bastia	Equivalent electrical energy	5.441.958,42	2.503.300,87	11.456.585,26	8.517.927,71
	Thermal energy	6.014.626,84			
·Toulon	Equivalent electrical energy	40.862.317,01	18.796.665,83	61.954.408,81	39.888.757,62
	Thermal energy	21.092.091,79			
·Nice	Equivalent electrical energy	5.347.814,70	2.459.994,76	8.671.454,05	5.783.634,11
	Thermal energy	3.323.639,35			
·Genoa	Equivalent electrical energy	326.381.972,16	150.135.707,19	537.823.591,55	361.577.326,59
	Thermal energy	211.441.619,39			

*Source: Authors' own elaboration on TDI RETE-GNL and SIGNAL INTTERREG ITA-FRA Maritime 14-20 Projects*

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# Implications for research/policy

## ➤ Academic implications

- ✓ The conceptual framework contributes to the academic debate on **port energy management** by designing and empirically testing **ad-hoc KPIs** capable to estimate port energy consumptions from rough data inputs.
- ✓ A number of alternative KPIs are discussed and proposed: the indicators pave on the **measurement of energy consumptions** (kWh) per spatial areas (e.g., sqm of land), traffic flows, process outcomes, etc.
- ✓ Several categories of terminals and concessionaires are examined and compared.

## ➤ Practical implications

- ✓ Large amount of **original data**, enabling to estimate port energy consumptions when updated information are not available.
- ✓ Standard KPIs can be used by terminal operators and port operating companies for benchmarking their energy consumption and monitoring/improving their **energy efficiency** levels.

## ➤ Implications for policy makers:

- ✓ Providing data for supporting policy makers when developing path-breaking energy policies, port master plans and funding schemes directed to energy savings and emissions reduction.

# Limitations & further research

- Empirically testing the selected KPIs on a larger sample of ports/facilities in order to estimate the bias related to each of them.
- Jointly adopting more than one of the KPIs for each terminal category for ironing out potential errors.
- Customizing KPIs in order to consider **business model specificities** within the same type of terminal (e.g. automated vs. traditional container terminal).
- Introducing additional KPIs for investigating also the **environmental impact** of the port





**Thank you for your  
attention**

## **Key Performance Indicators for measuring energy efficiency in port terminals**

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