Ports Energy and Carbon Savings

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Research report on existing methods appropriate to carry out comprehensive energy audits in ports

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Table of contents

Table of figures

1. Introduction

Ports and the wider maritime industry are highly dependent on fossil fuels. Concerns over rising energy prices and greenhouse gas (GHG) emissions are driving investment and research into alternative energy technologies. Within ports electricity usage and its associated primary energy consumption are important contributors to carbon and other GHG emissions. The types of fuel use at the port and electricity generation in a region are a primary driver of GHG emission intensity (Weber *et al.*, 2010). Improved efficiency of generation and industrial use systems are therefore important as a method to reduce GHG emissions and reduce financial cost. Investment in the reduction of energy provides a relatively predicable and immediate impact on environmental and financial performance resulting from lower bills and reduced emissions from energy sources.

Energy audits and energy audit programmes are a commonly applied and effective instrument to overcome barriers to energy efficiency (Thollander *et al.*, 2012). Similarly, carbon footprinting and life cycle assessment (LCA) techniques have been applied to identify sources of GHG emission and reduce energy related emissions.

This report considers the context of ports as energy users and generators, highlighting specific issues relating to the definition of the port system. Existing methods for the assessment of port energy use, efficiency, and related GHG emissions are discussed. Within this context consideration is given to the application of these methods to interventions to reduce GHG emissions related to energy. This report concludes with recommendations for the further development of tools and methods to assess the potential for energy saving and other interventions in ports.

2. Energy Audits and Carbon Footprints

2.1.Introduction

Closely related to improvements in economic and environmental performance, energy efficiency has become an important topic for corporate management (May *et al.*, 2015). Over recent years government policies, business objectives, and private households have begun to address energy efficiency topics, driven by concerns of climate change, resource scarcity, and rising energy prices. The Europe 2020 Strategy aims for a 20 percent reduction in overall energy use by 2020 against a 2005 baseline. Consequently avoiding energy wastage through energy awareness and understanding are crucial to business competitiveness and long-term sustainability.

Energy audits have become a commonly applied and useful tool for the management of energy consumption within industry, private residence, and business. Audits provide a mechanism for organizations to understand their energy usage and identify areas for efficiency improvement. Implementing energy audits and subsequent management strategies can be highly beneficial for industrial companies for economic, societal, and environmental reasons. Closely related, the carbon footprint provides a mechanism to identify and manage carbon emissions associated with energy use.

2.2.Energy Audits

Energy audits and their related programmes are a widely applied instrument for the purpose of identifying barriers to and improving energy efficiency. Despite the widespread application and clear importance of energy audits, and the wide range of energy audit programmes operational internationally, there is a lack of agreed consensus on definitions, methods, and tools (Thollander et al., 2012). The term 'energy audit' is commonly used and has a range of meanings depending on how and where it is applied. Many energy audit methods have been developed, but are technology or application specific. At its most basic, the process consists of a systematic examination of the use of energy in a system or facility. Generally audits are applied for the identification of energy losses, their quantification, estimation of conservation potential, and the development of technological options for energy conservation, and the economic feasibility of those options. However, while the general objectives of energy audits are widely accepted, the methods are not standardized (Bhatt, 2000). An 'energy audit' can describe a broad spectrum of activities ranging from simple visual walk-through inspections to detailed computer simulations of building energy physics. There is no single agreed-upon set of defined terms for the various types and levels of energy audits. Broadly there are two significant characteristics relevant to categorizing types of energy audits – level of detail, and physical extent (i.e. the size of the audited system in terms of its subsystems and components) (Canadian Industry Program for Energy Conservation and Canada, 2011). Generally one would expect that, as the level of detail in an audit is increased, the physical scope would decrease and vice-versa. Various methods have been proposed that further disaggregate types of energy audit by the processes employed in their execution e.g. walk-through, utility cost, standard, and detailed audits (Krarti, 2011).

2.2.1. Types and levels of audit

The simplest form of audit, often considered a step in a more detailed process - a walkthrough (alternatively called a preliminary or screening audit) involves minimal interaction with site personnel, a brief review of operational energy costs, and a walk-through to identify areas for immediate improved energy conservation. Examples might include adjustments to heating temperatures, repairs to broken building fabric, or insulation on exposed pipework. Corrective measures are only briefly considered and more detailed investigation would be required to make informed decision on actions to be taken. However, the audit does provide for an identification of quick-wins and a method to prioritize projects.

A more detailed audit that examines the operating costs of a facility. Energy consumption and cost data can be interrogated over several years to provide patterns of daily, weekly, monthly, and annual energy use. The detail provided enables the identification of peak energy demand – both by location and time, the effects of weather patterns, seasonality. Where financial data are used to proxy energy data, care must be taken to ensure correct energy rates are applied.

These site-based methods represent bottom-up approaches to energy auditing. However, actual consumption data from sales records or feedstock records can be difficult to obtain, primarily due to the commercially sensitive nature of such data (Wright *et al.*, 2011). Point data from larger facilities may be available from legislative emissions reporting schemes; however this often does not encompass smaller installations or entities (Gurney *et al.*, 2002). Commercial and industrial energy consumption can be calculated, and thus audited, using local fuel sales data. However, this assumes fuel consumption at place of purchase, and may not accurately reflect the point of consumption (e.g. where purchase records for a production site are held at a geographically separate financial office). Alternatively, a top-down approach can be applied to provide comparable audit results. Aggregate data at the meso-level is used to attribute energy use to the sector, regional, and building scale based on ratio factors.

Gurney et al. (2012) describe a model to simulate energy demand based on building parameters combined with known local atmospheric emissions. The same study notes that this method is only suitable for large point source emitters. Therefore they describe a proxy estimation, whereby total national energy consumption statistics are divided by total national floor area by industry, allocated to the local level. A similar method, using publically available Dutch datasets, has been applied successfully to calculate energy consumption and savings potential for the Odijmond area (TNO, no date). Similarly employment by industrial sector can be used to pro-rata known national emissions (Tsagataskis et al, 2008). These methods rely heavily on the correct industrial classification of facilities in the local community, where facilities are incorrectly classified this will produce erroneous results.

In the majority of corporate settings investment for energy infrastructure must compete with other capital investment commitments. In both contexts investment decision making generally stress the financial criteria and expected return from the investment. Energy interventions propose a secondary concern through the general requirement for an expected return on carbon emissions reductions. The demonstration of these reductions can be clearly articulated with an inclusion of a carbon footprint assessment (section 2.3).

2.2.2. Energy efficiency and effectiveness

There are numerous pre-packaged methodologies and tools for the purposes of energy auditing (e.g. (Giacone and Mancò, 2012; Thollander *et al.*, 2012; May *et al.*, 2015), and equally numerous ways to categories and measure energy use and energy efficiency. For example improvements in the energy performance of buildings may be represented in terms of energy use per unit area (e.g. kWh/m^2), by occupation (e.g. kWh/FTE employee), by time function (e.g. kWh/yr) among many others (Thollander *et al.*, 2012). Importantly, there is no one universally accepted measure, in large part due to the differences in systems and their functions being audited. This make comparisons between sites and industries difficult. As a result a range of methods for the completion of energy audits have been developed (e.g. (Gurney *et al.*, 2012; Thollander *et al.*, 2012) with differing boundary conditions and applicable methods.

Common however, to all these audits is the objective of improved energy efficiency and/or reductions in associated CO_2 emissions. In physical terms efficiency is defined as the ratio between the useful output from a system and input of an energy conversion process. The EC (2006) defines energy efficiency as "a ratio between an output of performance, service, goods or energy, and an input of energy" (EC, 2006). Energy efficiency should not be confused with effectiveness – a highly inefficient system that wastes most of its input power, but performs its intended function is effective but inefficient. The efficiency term makes reference therefore to the desired effect. That is not to say however, that the system cannot be made more efficient; simply that system effectiveness must be maintained in the pursuit of efficiency. Additionally, the effort undertaken to improve energy efficiency should not be mitigated by the material and energy investment required for the intervention. Importantly this distinguishes an energy efficiency improvement measure as requiring to fulfil two specific functions – an improvement in energy efficiency with no negative effect on the function or performance of the system; and to demonstrate an energy saving across the life cycle of the intervention (Thollander *et al.*, 2012).

2.3.Carbon Footprints

The concept of the carbon footprint is closely related to the practice of energy auditing, with the data necessary for the calculation of a carbon footprint a commonly provided by some derivation of an energy audit. Indeed, the carbon footprint calculation is in large part driven by energy consumption within the system of study (Weber *et al.*, 2010). The term 'carbon footprint' has become a commonly used phrase to relate a unit of human activity with an amount of GHG emission (Wiedmann and Minx, 2008; L A Wright, Kemp and Williams, 2011; Turner *et al.*, 2012; Williams *et al.*, 2012). The exact definition of a carbon footprint varies, with the most basic commonality being a certain amount of some GHGs allocated to a level of human activity. Rooted in the term 'ecological footprinting' – a conceptual representation of the area of land required to provide necessary resources and assimilate pollution for a given activity or population (Wackernagel and Rees, 1996). However in the context of the carbon footprint, the term 'footprint' does not apply to a literal area or amount of land, instead being representative of the Global Warming Potential ($kgCO_2e$) (Williams *et al.*, 2012). GWP values are released by the IPCC, expressed as the equivalent amount of CO_2 for a given GHG that would have the same effect on climate forcing if emitted to the atmosphere. Commonly used as the GWP or climate change impact category in Life Cycle Assessment (LCA). The calculation of the carbon footprint is based on the principle of an emissions factor, an emissions rate per unit of fuel or energy consumption, per activity (Wright *et al.*, 2011).

The majority of carbon footprint definitions and methodologies follow the World Resources Institute/World Business Council for Sustainable Development terms of scopes: scope 1, direct emissions; scope 2, emissions from electricity consumption; scope 3, indirect emissions (The Greenhouse Gas Protocol, 2005). The final scope is often considered 'optional' and subjective in its application, due to the complexities in the application of cut-off criteria for external upstream process (Wright, Kemp and Williams, 2011). Boundaries of carbon footprints are frequently set in keeping with convention or based on selective judgement (Suh, 2006).

Direct emissions (scope 1) are generally associated with the combustion of fossil fuels, and other processes that lead to GHG emission (e.g. anaerobic decomposition and CH_4). Direct emissions are generally regarded as being those over which the subject of the carbon footprint has the highest level of control or influence (Matthews, Hendrickson and Weber, 2008; Williams *et al.*, 2012). Some fugitive emissions may also fall within the category of 'direct' emissions – for example the escape of natural gas (CH_4) from corroded pipes, or the release of VOCs from hydrocarbons (degrading to CO_2 in atmosphere). Scope 2 emissions cover those emissions associated with grid-connected and other indirectly supplied energy use, apportioned to end-users (Greenhalgh *et al.*, 2003).

Indirect emissions (scope 3) are those caused by the demands the subject of the carbon footprint places on the wider economy in which it operates (Wright, Kemp and Williams, 2011). Considering further out-of-boundary, non-electricity indirect emissions sources. For example, demand for materials derives demand for manufacture and processing. The responsibility for the GHG emission associated with this upstream process could reasonably be allocated to the consumer as the source of the demand (Lenzen *et al.*, 2007).

Emissions sources can also be considered in the context of life-cycle perspective: either as production related emissions, or up/down-stream process emissions (Kennedy *et al.*, 2009; Wright, Kemp and Williams, 2011; Wright *et al.*, 2011). Within the context of energy auditing, scope 1 energy related emissions, and scope 2 emissions are evidently of most interest. Scope 3 emissions may be considered out of boundary, these emissions are commonly associated with life-cycle emissions from products and supplied services (e.g. waste management, transport), outside the context of organisational energy management.

The Intergovernmental Panel on Climate Change (IPCC) guidelines emphasise the importance of following standardised, scientifically accepted principles, procedures and processes. In addition the guidelines make reference to 'tiers' of data complexity for emissions factor application. Tier 1 methods are simple and easy to apply relying on default national statistics. Tier 2 methods are characterised by more specific data and statistics. These methods are likely to require more work, but yield more accurate results. Tier three methods offer the most accurate results, but are also the most complex; utilising specific mass balance approaches to modelling. In practice, methods of calculation should be determined by the intended use of the footprint and the time and resources available for the calculations (Matthews et al, 2008). The tier concept is useful applied to both the carbon footprint and the energy audit, defining the extent of the detail and methods required.

3. The Port Context

Ports provide a novel and interesting context for the application of energy audit methods and carbon footprint techniques. Varying widely from sprawling industrial complexes to small niche marinas, ports primarily operate as logistics platforms for the transfer and movement of people, goods, and services. In doing so they need to consider not only the requirements of the senders and receivers of goods and services; but act as business partners alongside shipping companies, terminal operators, forwarding companies; whilst also operating as landlords to occupying industries (Carbone and Martino, 2003). In the context of rapidly adapting competition in globalised markets, integrated transport systems, and new transport technologies, port authorities are presented with significant functional and structural challenges effecting the management of their operations (Robinson, 2010). Subsequently the boundaries of ports and harbours can vary significantly depending on a range of circumstances, including: geographical opportunity, socio-political factors, or the prevailing economic conditions at the time. This, in turn, may have significant ramifications for energy audits and emissions inventories (Villalba and Demisse Gemechu, 2011).

This section explores competing definitions of ports as geographic places, administrative units, and as supply chain components; with each perspective explored within its relevance and impact on energy auditing and carbon footprint. A consideration is also provided to the role of marine transport within the carbon footprint of ports.

3.1. Ports as places

Historically ports have served as natural sites for the transfer of seaborne goods to or from inland modes of transport – an interface between sea, rivers, roads, and rail (Carbone and Martino, 2003). Simply put, the port is a place that handles ships, cargo, and passengers. In geographic terms the port serves as a transfer point for goods and services. A port may be defined in a variety of ways, from a place on a waterway with facilities for loading and unloading ships; to a city or town on a waterway that includes such facilities; to being the waterfront district of such a city. It could be defined as a place along a coast that gives ships and boats protection from storms and rough water; a harbour; or a point of entrance to, or exit from, a network. Whichever, Historically ports have served as natural sites for the transfer of seaborne goods to or from inland modes of transport and represent therefore– an interface therefore between sea, rivers, roads, and rail (Carbone and Martino, 2003). Simply put, the port is a place that handles ships, cargo, and passengers. In geographic terms the port serves as a transfer point for goods and services. Modern definitions also include a multi-functional logistic centre but simply put ports are at the intersection between transport, trade and customs.

Over time, port developments have been closely linked with technological changes. Ships have been, and still are, increasing in size, whilst new technology such as containerization has become more and more important. The result has been an increase in the scale of port operations, with some ports being able to move with the times whilst others have stagnated. Key requirements have been the ability to enable maintained depths of water within berths; safe, clearly marked, deep-water approach channels; arrangements to ensure the safety of navigation; the provision of land space to provide quayside, ideally with development potential; and a developed multi-modal transport infrastructure to and from the port. There is no point having an efficient port if you can't move the cargo to it or away from it in an equally efficient manner. The speed and efficiency of port operations are crucial to the shipping industry as ports represent the place where maritime risks are highest; where cargo can be damaged and/or stolen; and where accidents most often occur. They are also the place where delays are most likely; and hence where costs are incurred.

Shipping and ports are symbiotic and have shaped the modern world, through enabling the extraction of resources, encouraging innovation, leading to variations in geospatial and geopolitical developments, including migration and urbanization. They have therefore had both directly and indirectly some of the biggest impacts, economically, culturally, socially and environmentally on our planet.

A port's distinctive character is shaped by its' traffic, trade, local circumstances and environment. A ferry port may have markedly different issues than those of a container port though both will have a number of common features. Ports for example provide a variety of services including victualing, stores and storage, bunkering, ship repairs and dry docks; and are also characterized typically by associated industrial development and port-operating companies located on the port's land holdings, some of which may act as support industries.

A useful characterization of port services and functions as a well-considered theory is the Anyport Model developed by Bird (1963) as the Anyport Model. This describes how port structures develop in space and time, and how in this context the port is heavily constrained by geographical factors (Bird, 1963). This model also is provides a useful context for consideration of the services and functions contained within the geographically constrained boundaries of the port. This might provide a useful model through which carbon emissions may be considered. Under this approach emissions occurring from the services rendered by the port authority and those industries operating within the port are included in the carbon footprint; placing emphasis on the landside landward operations of the port authority and port operators.

The advantage of the geographic definition is that it provides for an easily definable boundary for the port. Individual operations within the port can then be further disaggregated by operator or location for improved data granulation. Ports and harbours can apply these methods to recognise the energy and associated emissions arising from within their geographical operations. However, where these methods can recognise and stimulate local policy and response, they are not sensitive to the role of specific organisations within the port, nor the wider supply chain emissions occur outside the geographical boundaries of these communities.

3.2. Ports as economic and administrative units

The restructuring of ports and harbours through corporatization and privatisation as a result of successive application of competition policy has taken place in many countries has changed a sector previously delivered through statutory service (Robinson, 2010). Private corporations with their own supply chain arrangements, commitments, and customers now commonly operate within the confines of port authority areas. Essentially the port environment has become a 'micro' community of businesses and organisations, within the wider environment of the cities and communicates they serve.

Purely geographic approaches to energy audits, carbon footprints, and life cycle methods within ports would not be sensitive to the multiple organisations operating within the port confines. Instead accounting all emissions arising from within the boundary. As these operations are tenanted to the port operator and operate as private companies, under a geographic model energy and emissions would be allocated to the operator rather than the port. This arguably is no longer under the remit of the emissions inventory of the port authority, as fiscally the port operator has no influence over the private operation. However, it is still within the wider geographic boundaries of the wider port. The port authority also has the responsibility to provision power and services for tenanted operations. Therefore, influence can be exerted over port tenants (e.g. cold-ironing systems). The effect is enhanced in commercial marina and harbour type environments where the operator is a service provider to private individuals rather than companies. Ports may be viewed as a large incumbent landlord organisation with their boundaries defined on operational and financial controls. Although it is important to establish mechanisms to consider the impacts of shared services.

This differentiation can be achieved through representation of the port authority carbon footprint with the addition of the carbon footprint of provisioned services to other port tenants. For example the port authority may operate an office facility and loading dock. Responsibility for these emissions is allocated to the port authority directly. Secondary provision of services by the port authority to tenants (e.g. electricity) can then be reported separately providing an incentive for the reduction of emissions associated with shared services.

3.3. Ports in derived-demand supply chain systems

Ports do not operate as solely autonomous entities, but rather as actors in a complex networked supply chain (Carbone and Martino, 2003). Ports and harbours are nodes for the transfer of goods and people between transport modes. Arguably therefore the operation of a port includes the wider system of maritime transport as a mutual derived logistics function (i.e. the port exists because of the demand for service, and the maritime operations visit because of the port). Ports are responsible for a range of production based emissions from a range of sources (e.g. port transport, manufacturing), but also for a demand led transboundary range of emissions (e.g. grid-connected electricity; imported products; water supply; maritime transport). As a result, territorial based approaches to port and harbour footprints fail to capture the full range of emissions associated with ports and harbours.

At the city level the metabolism of the city and its major functions can be modelled using a combined approach, whereby key in-boundary flows are modelled using PA and key flows of energy and material are modelled in a demand fashion (Ramaswami *et al.*, 2008; Chavez and Ramaswami, 2013). "Transboundary" (alternatively termed "territorial-plus", "geography plus" or "metabolism based") approaches add out-of-boundary emissions associated with economic demand to territorial emissions, with the exact boundary conditions and scope varying between studies (Ramaswami *et al,*2008; Wright *et al*, 2011a; Baynes and Wiedmann, 2012; Chavez and Ramaswami, 2013). Top-down consumption based methods include all emissions along the supply-chain of goods and services, with boundary conditions defined by final consumption of households and governments (Wright, Kemp and Williams, 2011). The consumption approach is useful in the informing mitigation of emissions associated with household and government consumption; but is less applicable to ports as logistical operators, as they do not serve as final consumers in the supply chain. Much of the port logistical operation would be allocated through the flow of products and services to the final consumer, rather than to the port.

3.4.Marine Transportation

There is considerable debate around national and regional GHG inventory's regarding the equitable apportioning of emissions from ocean-going and other seaborne vessels (Wright *et al.*, 2011). Action for the reduction of emissions from these sources is difficult until responsibility is allocated and leadership can be established. Within the context of ports there is evidently a symbiotic relationship between the port and vessel operators. However, the operation of marine transportation is not within the operational control of the port *per se.* Some studies suggest inclusion of emissions from ships transiting to or from ports (Wright *et al.*, 2011). Essentially accounting half of the vessel transit. This effectively represents a demand function of shipping for the port (i.e. the port exists due to the demand of international trade). This accounting is particularly important at the national and sub-national inventory levels, else a significant proportion of international emissions and energy demand are excluded. Further studies challenge this definition and suggest emissions be included once the vessel enters the port navigational control area. For example Villalba and Gemechu (2011) in their study of the Port of Barcelona suggest inclusion of emissions one nautical mile from the port, as this is the point at which ships begin to use auxiliary engines for transit into the port. Similarly, the Port of Huston sets a boundary of 45 nautical miles as ships must transit channels controlled by the port navigational authority before arrival at the port. This effectively recognises the role of the port as service provider to the shipping organisation (WPCI, 2010).

Shipping emissions are likely to constitute a significant component of the carbon footprint of a port, in the case of the city of Southampton (calendar year 2008), emissions from shipping comprise a dominant proportion (36%) of the total city carbon footprint, effectively dwarfing the footprint of the port (Wright, 2014). Based on a half trip metric, this would make any meaningful attempt by ports to decarbonise negligible. However the decarbonisation of ports as a component within the supply chain is important and should be viewed as a component within a wider system. For this reason it is important to view any effort to reduce carbon emissions within the context of the system in which they are framed. For example, within the PECS project, the replacement of a link-span at the Port of Portsmouth (Figure 1) would provide negligible carbon savings within the context of the emissions from the port with the inclusion of shipping operation, but through consideration within the context of the loading operations of the port provides for a meaningful effort in the reduction of port related carbon emissions.

Based on this rationale emissions from marine transportation are considered to the limits of pilotage (or similar distance in the case of commercial marinas). It is deemed that this provides a fair representation of the limits of control of the port, and incentivises marine transportation based carbon reduction measures (e.g. cold ironing). The issue of context specific carbon savings is address through the use of a 'function unit' type approach (section 4).

4. PECS Approach – Unit processes and function

The PECS project specifically considers four ports –Ostend; Ijmond; Portsmouth; and Hellevotsluis. Within these ports two additional operating partners – Indaver and Blue Power Synergy - are considered in providing a series of case studies which will demonstrate a range of ports and port operating environments. The application of energy audit and carbon footprint methods to these case studies will demonstrate energy and carbon saving outcomes. However, a number of challenges exist. Namely, the need to disaggregate energy sharing structures to enable fair and equitable assignment of emissions responsibility; the need to demonstrate improvement in energy performance, whilst maintaining system effectiveness; and the requirement to demonstrate carbon reduction.

The development of energy sharing and cooperation structures is key to overcoming the first challenge and will also help in addressing both system-based energy efficiency relating to a more holistic port view, and reductions in carbon emissions. This is the subject of Outputs 5 and 6 of Work Package 1, where a methodological approach will be developed and employed with regards both Ijmond and Hellevoetsluis.

Overcoming the challenges of demonstrating improved energy and carbon efficiency, whilst simultaneously maintaining system effectiveness may be overcome through the application of a unit process approach to the audit and footprinting method. Function describes the main function performed by the system and indicates how much of this function should considered in the assessment. A unit process then describes the smallest unit within that function for which data are collected or are required. Through this metric all energy consumption and related GHG emission are allocated to a single functional output of the system. This has the added benefit of defining the metric to be used to measure the savings achieved through reconfiguration of the system. Additionally the approach attributes only the energy required for that specific function, and clearly representing the purpose (effectiveness) and efficiency of the system. For example within the context of the PECS project. The Port of Portsmouth is installing a linkspan (Figure 1). The function of the linkspan is the loading and disembarkation of vehicular traffic from passenger ships. Within the context of all port operations the linkspan represents a singular point of energy consumption. When considered as a unit process, only the linkspan is considered. Thus the argument is created that the linkspan may be replaced to achieve energy and carbon savings relative the linkspan system, within the context of the need to provide vehicle movement capacity. Further assessment can then be made to assess the effect of any increases in effectiveness of the system on energy consumption (e.g. increased vehicle capacity resulting in faster load times).

Figure 1 Examples of the unit process approach applied to the linkspan intervention to be undertaken by the Port of Portsmouth, link span intervention highlighted.

5. Recommendations for energy audit and carbon footprinting tools use in ports

Increasingly, the management of energy and related GHG emissions is becoming an important issue for industry and business. Energy audits provide a mechanism to assess energy consumption, and provide recommendations for performance enhancement and efficiency gains. Carbon footprints offer a supplementary methodology to quantify the GHG emissions associated with energy consumption and to measure resultant savings. Ports present an interesting and novel environment to apply these methodologies. Defined as both a place and as a functional unit within a wider supply chain, the port environment presents distinct and unique challenges. Considering these challenges, a series of recommendations are made within the context of the PECS project:

- For the purpose of the PECS project, the scope and boundary of an energy audit applied to a port should be defined by context of individual port, specifically noting:
    - Marine transportation should be calculated to the limits of pilotage (or equivalent) to encourage consideration of methods to reduce the associated port related carbon footprint.
    - Mechanisms to recognise energy sharing within the port context must be developed. It is suggested that these are defined on both operational control and financial benefit of energy provision. This is necessary to incentivise both energy reduction, energy efficiency, and supply decarbonisation.
- The greatest effectiveness, and widest application of the developed energy auditing methodology is likely to be achieved where a universal and easily applicable approach is achieved.
    - It is recommended that a calculation tool using port level data, complimented by top-down regional data is developed. This would enable a minimal effort/maximal returns approach by ports for the initial identification of energy consumption and areas of potential savings.
    - The audit and carbon footprint should be conducted at two boundary levels – a) determined on geographic boundary, b) defined on administrative/political boundary of study organisation. This will provide for multiple levels of energy audit and carbon footprint to demonstrate the effectiveness of port and intervention carbon savings.
    - A unit process approach is necessary to demonstrate the carbon savings required within PECS project. This approach would also enable ports to assess the relative effectiveness of energy saving interventions. This must be placed within the context of the wider carbon footprint of the port to show effectiveness at both levels.
    - Tier III carbon footprint emissions modelling should be used where practicable, in order to provide accurate, reliable, and actionable results. Data to be utilised from local records where possible, regional or national databases, or modelled on average activity emissions factors where needed.

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