Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Full length article

Role and potential of the circular economy in managing end-of-life ships in China

Benjamin Steuera,d,e,⁎, Margarethe Staudnerb,d, Roland Ramuschc,d

Abstract

China’s circular economy has made notable progress since the 21st century and shaped various industry segments. Among these, ship recycling has been particularly outstanding as it evolved exceptionally fast and assumed an internationally leading role. In this article, we present field survey findings on recycling standards and recovery capacities regarding the material flows at Chinese shipbreaking yards, which overall perform comparatively sustainable. However, recent policy and market developments have induced the sector’s decline, which at present seems to threaten the very fundamentals of circular economic management for obsolete vessels in China. Given these limited prospects for traditional recycling approaches in the near future, the article proceeds to evaluate alternative circular economy management options for Chinese ship recycling facilities to manage end-of-life vessels. Based on quantifications of hidden potentials in ship supply, value and material contributions to the domestic circular economy, technical and market specific conditions for material recovery as well as other circular economy practices, we find that ship repair and refurbishment may offer the most promising alternative to recycling for Chinese shipbreaking yards.

1. Introduction

In waste management (WM), the recycling (or breaking) of end-of-life ships (EOLS) has long been a highly marginalised topic only addressed by research in recent years. This is reflected in number and time of publications on ship recycling: the records of Scopus and ScienceDirect for example indicate that out of 76 articles between 2001 and 2019, 66 were only published after 2011. Both recency and paucity of academic engagement with this field is surprising given the potentials as well as the challenges discarded vessels present for WM and the Circular Economy (CE) at large. On the one hand, waste ships contain large quantities of recyclable components such as liquid quenched and tempered steels, copper, titanium alloys, aluminium and electronic equipment with inherent recyclable components (Choi et al., 2016). Roughly calculated, 85–95% of materials in EOLS have a high recovery value (Choi et al., 2016; Du et al., 2017). This particularity renders the ship recycling sector significant for the CE. Firstly, proper vessel dismantling prevents pollution by uncontrolled leaking of hazardous waste. Secondly, subsequent reprocessing of secondary steel and non-ferrous metals reduces the need for virgin material inputs in production processes and thus helps closing the loop of material flows in the economy.

On the other hand, ship recycling constitutes a labour-, cost- and infrastructure-intensive process that bears the danger of severe environmental contamination. The dismantling of vessels inevitably releases hazardous streams such as waste oils, glass fibre, solid foam, asbestos and polychlorinated biphenyls. Respectively required treatment procedures are cost-intensive and in turn diminish profits for ship recycling facilities (SRFs) (Du et al., 2017; Jain, 2017). Ship owners, which are the upstream link of vessel transactions, are thus faced with the choice to either act responsibly and transfer obsolete ships to certified yards or maximise their profit and deliver ships to substandard and environmentally harmful informal dismantling. In the absence of a binding international regulatory framework that could set forth trans-boundary

Abbreviations: BO, Beneficial owner; CE, Circular Economy; CNY, Chinese Yuan; EOLS, End-of-life ship; LDT, Light displacement tonnage; MFA, Material flow analysis; NSWMC, National Solid Waste Management Centre of China; PRC, The People’s Republic of China; SRFs, Ship recycling facilities; WM, Waste management

⁎ Corresponding author at: The Hong Kong University of Science and Technology, Division of Environment and Sustainability, Room 4362, Clear Water Bay, Kowloon, Hong Kong.

E-mail address: bst@ust.hk (B. Steuer).

https://doi.org/10.1016/j.resconrec.2020.105039

Received 18 December 2019; Received in revised form 20 June 2020; Accepted 1 July 2020
Available online 10 September 2020
0921-3449/ © 2020 Elsevier B.V. All rights reserved.
floating waste materials is particularly problematic.

In light of these challenges it comes as no surprise that the vast majority of ship recycling activities is conducted in the global south, where regulatory standards and labour remuneration is low (Alam and Faruque, 2014; Hiremath et al., 2016; Choi et al., 2016). Additionally, dismantling EOLS locally provides job opportunities and constitutes a source of scrap steel, which serves as secondary raw material for local manufacturing. Figures from 2019 on the global ship recycling sector underscore the regional concentration of ship recycling activities in low- and lower-middle-income countries, with Bangladesh (58%), India (27%) and Turkey (9%) constituting the three major national players in the field. Respectively, most of the country-specific research work (51 out of 76 articles) listed in Scopus and Sciedirect has been centred on three, four international frontrunners in ship recycling.

What these figures do not reveal, is that SRFs in the People’s Republic of China (PRC) were dominating global ship dismantling until very recently. Their rise to international prominence began after the country’s reform and opening policy in the late 1970s. By the mid-1990s China represented the largest global ship recycling nation with a market share of 50% (Zhao and Chang, 2014). Chinese SRFs’ performance continued to thrive until 2013 when China, together with India, Bangladesh, Pakistan and Turkey, held a market share of 92–98% in globally dismantled tonnage – the equivalent to approximately 29 million tons in processed vessels1 (Mikells, 2013; Choi et al., 2016).

Facing increasing international competition, especially from recyclers in South Asia operating under low-costs and low environmental standards, Chinese policymakers opted for a pro-environmental strategy in the early 2000s. As part of a larger national initiative towards the CE, Green Ship Recycling guidelines were set forth to raise dismantling benchmarks at SRFs (Ma et al., 2014). Doing so also constituted a strategic diversification in the international market that provided responsible ship owners with a sustainable alternative to more polluting practices in South Asia. The reasons for the significant decline in Chinese shipbreaking are mostly of a domestic nature: Institutional as well as market developments, i.e. the PRC’s waste import ban and declining scrap steel prices, have severely curtailed the sector and seem to have heralded in the end of China’s sustainable ship recycling on the international stage (Steuer et al., 2020).

Given the decline in traditional ship recycling, this article addresses the question on which alternative CE practices exist for managing EOLS in China. In search of a comprehensive answer, the first section presents a factual analysis of recycling operations at selected SRFs. We analyse findings from field surveys and material flow analyses (MFAs) at ship recycling yards, which provide insight into applied, national vessel recycling standards and methods as well as an achieved material recovery performance. Given that Chinese shipbreaking will continue to decrease in volume and significance, the subsequent sections complement the findings from surveyed SRFs by (1) assessing the theoretical potential for further ship dismantling in China based on documented vessel quantities, previous trends and ownership structures (Section 4.1); (2) ascertaining quantitative as well as value-specific output from ship recycling to the Chinese CE (Section 4.2); and (3) discussing the technical and economic factors that impair the use for secondary materials recovered from EOLS in China (Section 4.3). Given the clear limitations for ship recycling in China the concluding analytical section therefore elaborates on potential alternatives for CE management of EOLS in the PRC (Section 4.4).

2. Materials and methods

The data and material resources presented in this paper were gathered in the course of two stages. In first instance, the authors had conducted an EU-funded research project during 2013–2016 on sustainable ship recycling in China (see the acknowledgment section). The primary objective was to assess recycling practices at major Chinese SRFs so as to derive technical and policy recommendations to strengthen material recovery and improve environmental standards. In addition, the project aimed to evaluate the sector with respect to provisions as set forth in the Hong Kong International Convention for the safe and environmentally sound recycling of ships and the Regulation (EU) No 1257/2013 on ship recycling.

In regard to the sample size, the project covered 21 Chinese SRFs, out of which six recycling yards, which best represented the diversity of China’s treatment landscape, were selected for material flow case studies.2 After consultation with the companies on matters regarding data availability, Chinese project partners visited the SRFs in order to conduct material flow assessments. In a separate step, the authors together with Chinese partners undertook field investigations at another six selected yards in 2014 and 2015. This was done to complement the abstract findings on material flows with a mix of quantitative and qualitative data sets on economic performance, environmental protection and worker safety measures, recycled and disposed of fraction types and quantities, as well as corporate development strategies. Each survey typically lasted between four to five hours per yard, and the essential data sources available to us were presentations by SRF representatives, semi-structured interviews with head management and guided tours at the yard sites. Limitations to the study pertained to the comparatively small sample size and that SRFs for the survey could not be selected based on comparable characteristics. These impediments arose due to that participation of SRFs in the project was voluntary with no immediate incentives being offered.

The initial intention was to use these data to assess potential and contribution of ship recycling to the Chinese CE. However, during the project duration, increasing signs of a substantial downturn in recycling activities emerged, which has been confirmed by representatives of visited yards (Interview 4, 2015; Interview 5, 2015; see also NBSE, 2014). While we discussed the dynamics behind this development elsewhere (see Steuer et al., 2020), the question on the future role and potential of the CE in EOLS management in China remained unaddressed. To engage with this problem, we initiated a second stage of data and information gathering in order to track the development of the sector. By means of desktop research, relevant materials were drawn from various online repositories such as NGO and business databases as well as analytical business reports. Doing so helped overcome the aforementioned paucity in secondary research and enabled an analytical extension beyond the original CE assessment of selected yards.

3. Assessment of ship recycling performance in China

3.1. Recycling methods and standards

In general, ship recycling methods can be distinguished in regard to environmental sustainability, worker safety and technical complexity. The least demanding practice is called the ‘beaching-gravity method’. Being widely applied in India, Pakistan and Bangladesh it implies manoeuvring ships at full speed during high tide against a beach for subsequent manual dismantling. As an essentially low-cost method, it entails severe negative externalities for human safety and the environment due to uncontrolled disintegration of the carcass and direct waste emissions into the sea. Ranging higher in environmental soundness and worker safety is the ‘landing method’, which is practiced in Turkey. In contrast to beaching, vessels are steered towards and hauled up onto a concrete slipway, which facilitates the containment of spills

1 In this context of this paper “ships” and “vessels” refer to vessels being equal or larger than 500 gross tons.

2 Due to the sensitivity of these data, the SRFs at which the MFAs were conducted, requested to remain anonymous.
and subsequent clean-up processes. Similar in terms of environmental protection, yet safer for workers is the practice of ‘alongside-’ or ‘pier-side breaking’, which constitutes the most commonly practiced method in China, the EU and the US (Choi et al., 2016). Hereby, vessels are berthed along a quay for dismantling via the use of machinery on land. In a final step, the remaining hull is either lifted out of the water for final dismantling on land or in floating dry-docks. Fluid emissions that enter the water can be contained (via oil booms) and cleaned up subsequently. Finally, the use of dry-docks and floating docks constitutes the cleanest and safest means in ship recycling: The probability of polluting the surrounding environment is comparatively low and the danger of working accidents is reduced significantly (Choi et al., 2016; Jain, 2017).

As for the situation in China, the local ship recycling sector has strived to achieve improved levels of environmental protection and worker safety. According to related research, China and Turkey constitute the first two countries that have institutionalised relatively reliable standards for environmental protection and worker safety in ship recycling (Du et al., 2017). Having moved from beaching to alongside- and floating dock breaking, many SRFs established modern reporting systems and implemented international standards pertaining to environmental management (ISO 14,001), occupational health and safety (OHSAS 18,001) as well as quality management (ISO 9000) (ibidem).

Our field investigations at six major Chinese SRFs confirmed the use of such advanced ship recycling practices. Operations at the yards featured alongside breaking (Fig. 1) including the use of oil booms, the application of floating docks (see Figure S1), waste water treatment facilities (see Figure S2) as well as asbestos storage and pre-processing installations (see Figure S3).

By virtue of implemented ship recycling regulations, the yards visited in the course of the surveys adopted a nine-step-dismantling process (see Figure S4). The initial preparation phase includes the general inspection of the vessel and its technical and operational records. Subsequent cabin cleaning and interior equipment dismantling aim at removing loose objects, instruments, devices and equipment as well as potentially explosive liquid and gaseous matters. In the following five phases the ship is then dismantled in a top-down manner, which in final instance requires the hull being lifted on a dry or floating dry-dock for final dismantling. In a concluding step, a complete site cleaning has to be conducted, which also requires containing all hazardous liquids and absorbing them via emission channels to treatment facilities.

While such achievements are laudable, as they constitute substantial steps towards sustainable operations, the overall advancement of the sector is uneven. Preceding, survey-based research for example had observed that, in terms of environmental protection and worker safety, ideal and less ideal practices occurred side by side at the same yard (Du et al., 2017). Similarly, our field surveys showed that levels of effectiveness in pollution prevention varied among the individual SRFs. Notably positive practices were observed in regard to wastewater treatment, asbestos removal and storage as well as the documentation and handling of hazardous waste. Wastewater systems normally feature a six-step separation process that initially serves the separation of water from oil. After that the waste water passes through a sewer system into SRFs’ waste water treatment plant, where it undergoes various treatments and is tested for pollutants, such as bromine, zinc, lead, cadmium and total suspended solids before discharge (Interview 1, 2014; Interview 2, 2014; Interview 3, 2014). Such installations are rated as highly-cost intensive with around 20 million CNY (3.2 million USD in 2015 prices) in capital expenditure and are subject to frequent inspection by local environmental protection bureaus (EPBs) (Interview 5, 2015). Among the hazardous waste fractions, asbestos is a key item of pollution management at SRFs and therefore substantial attention is given to storage and worker training. Several interviewees stated that training for personal handling this fraction was increased and that personal protective equipment as well as storage and pre-treatment facilities were upgraded in recent years (Interview 1, 2014; Interview 3, 2014; Interview 4, 2015; Interview 5, 2015). Some SRFs even went further and captured asbestos in impermeable containers and designated buildings for transport to landfill facilities (Interview 1, 2014; Interview 6, 2015). Possibly the most notable efforts were taken in regard to hazardous waste documentation and delivery. Hazardous waste streams have to be documented according to source, type and quantity at instances of generation, delivery and final processing. In a subsequent step, the recycler as well as the final processor has to independently send the waste stream records to the local EPB for verification (Interview 2, 2014; Interview 3, 2014; Interview 5, 2015).

Contrary to these positive achievements, we also found instances of less optimal management. During the field surveys, necessary environmental protection safeguards were found to be lacking in some cases, e.g. open-air storing of dismantled, oily machinery parts on a permeable surface. Moreover, it was not possible to ascertain the actual dimension of secondary pollution arising from the recycling process as
neither yards nor local environmental authorities had collected respective records on that matter. Narrative evidence provided by all SRF representatives confirmed that pollutant emissions from fires and leakages had occurred in the past, however, due to intensified controls the numbers of such incidents were kept to a minimum (Interview 1, 2014; Interview 2, 2014; Interview 3, 2014; Interview 4, 2015; Interview 5, 2015; Interview 6, 2015). In summary, the responsibility for poorly implemented environmental protection measures are in first instance borne by the SRFs. Yet, ultimately these weaknesses also stem from an insufficient codification of pollution prevention benchmarks in China’s regulatory framework on ship recycling (compare Steuer et al., 2020).

3.2. Material recovery performance

Recycling EOLS features a considerable CE potential as the majority of materials extracted from ships can be recovered for being used as secondary raw materials. Findings from ship recycling practices in different regions uniformly indicate that reusable secondary resources range between 90% (Hsuan and Parisi, 2020) and 98% (Choi et al., 2016; Yin and Fan, 2018) of an EOLS’s light displacement ton (LDT) weight. Herein, steel is of particular importance as it constitutes the largest fraction (70–85% of a vessel’s LDT weight) (Choi et al., 2016) and simultaneously provides the biggest portion of revenues for ship recyclers (Du et al., 2017). Another 10% of dismantled materials are non-ferrous metals inherent in machinery, appliances and devices on board, which similarly represent valuable inputs for metal smelting enterprises (Choi et al., 2016; Du et al., 2017).

The material flows at the six surveyed shipyards revealed similar proportions of recoverable materials. Recovered materials from EOLS dismantling are in the range of 99%, whereas hazardous materials account for approx. 1% (For more details see Table S1). These figures are relatively higher than findings in secondary literature and stem, amongst other factors, from differences in waste categorisation. When going into detail on the single fractions, the MFAs show that amongst recyclable secondary resources scrap steel constitutes around 75% and non-ferrous metals account for 7.8%. Another sizable fraction are ship motors (9.6%), which may either be refurbished and reused or scrapped for its valuable contents. Of the remaining hazardous fractions (average 0.65%), around 6500 t (0.4%) were incinerated and the remaining 2900 t (0.2%) were transferred to landfill (Fig. 2).

After dismantling, the recyclable fractions are stored within the SRFs’ premises, which occupies a substantial area size (see Figures S5 and S6). Depending on the specific endowments of the yards, secondary recyclables are either delivered to nearby further processing facilities or treated within the premises of the SRFs. Some recyclers have installed specifically designed smelting furnaces to process scrap steel within their own yard. For example in Xinhui Shuangshui Shipbreaking Steel Co., Ltd steel scrap is directly fed into a furnace without prior removal of paint and processed into steel bars (Interview 1, 2014) (Fig. 3), a practice not uncommon in ship recycling (Rahman et al., 2016). According to interviews with corporate stakeholders, steel recovered from EOL-vessels features comparatively high quality levels: Around 20% can be directly re-used in construction works (e.g. repairing streets, piles for underground construction) while another 80% can after rolling be used for the construction of new ships (Interview 4, 2015; Interview 5, 2015).

Our impression of the visited yards was that the sector could indeed contribute to the CE on the global and domestic scale. Depending on global commodity price developments, Chinese SRFs were able to absorb large volumes of internationally flagged EOL vessels in the past (NGO Shipbreaking Platform, 2014, 2015; Mikelis, 2013; CNSRA, 2017; Eworldship, 2017) and thereby reduce harmful and polluting practices in other areas. Doing so entailed the additional benefit of supplying the domestic market with secondary raw materials. However, given recent developments in China’s domestic steel market and national regulatory structure, the Chinese ship recycling sector is facing an unprecedented decline that may even threaten its very existence (see Steuer et al., 2020). As these developments appear to imply a casu for traditional in EOLS recycling in China, the following sections aim to explore the future role and potential for continuing CE approaches in this sector.

4. Future role and potential of circular economic practices for managing end-of-life ships in China

4.1. Ascertaining end-of-life vessel quantities and past dismantling trends

The central issues impairing future dismantling activities at Chinese SRFs are the reduced availability of EOLS as well as the PRC’s waste import ban. The problem of limited supply has been indicated in recent findings by Yin and Fan (2018), who outline scrapping trends of the recent past. Their research shows that global ship recycling trends have peaked in 2012, which the authors attribute to policy responses and stimulus packages after the financial crisis in 2008. During this time countries like China offered subsidies to ship owners for scrapping vessels so as to spur productivity and counteract economic contraction. This pattern however entailed several implications: Firstly, after the intensive phasing out of EOLS, annual global recycling activities began to drop since 2012 with China featuring a particularly strong downward trend (NGO Shipbreaking, 2012–2019). Secondly, the world fleet began to grow in volume once the global economy picked up pace again and these new ships are far from reaching their end-of-life stage. Given the previous recycling peak during 1998–2002, at which many vessels had reached their natural end-of-life, and based on the artificially induced recycling wave in 2009–2013 as well as the current average lifetime of a ship of 25–30 years (Yin and Fan, 2018), we can tentatively project that the next large-scale decommission to be as late as 2030. But it can also be assumed, that the COVID-19 pandemic will most likely lead to an increase in ship dismantling. Generally it is possible to observe, that there is a negative correlation between economic growth and the number of ships sent for dismantling.

For Chinese SRFs, however, the challenge is less about when the international supply of EOLS rebounds, but whether they have access to it. This issue essentially relates to the waste import ban, which was issued by the Chinese government in 2018 and by extension includes waste vessels for scrapping (MEE et al., 2018). As can be discerned from Fig. 4 below, foreign-flagged vessels constituted the majority of ships dismantled in China in 2016–2018. In light of the waste import ban, a significant contraction of recycling activities at Chinese yards on the long term is most likely (Steuer et al., 2020), especially if shipowners prefer cheaper yards in the absence of binding international conventions.

While rigid in nature, the ban does not fully account for the aspect that EOLS affiliation is characterised by their beneficial owners (BOs) as well as their flag of convenience. It is a frequently encountered practice that BOs register their ships under the flag of a country other than that of the BO (“flags of convenience”). So theoretically, Chinese SRFs may still get hold of obsolete foreign flagged ships that are operated by Chinese BOs should they for any reason decide to reflag their vessels and register these in China. For assessing this hidden potential, which could in fact prevent severe operative reductions at Chinese recyclers, it is necessary to resort to past transaction patterns. According to records of the NGO Shipbreaking Platform, foreign flagged ships that belonged to Chinese BOs and were recycled in China constituted a median of 24% for all foreign flagged EOLS dismantled in the PRC during 2014–2018 (NGO Shipbreaking Platform, 2014–2018). In theory, and assuming that respective regulations were to be issued, it could thus be possible to oblige Chinese BOs to reflag their ships, transfer them to Chinese SRFs and by implication help to sustain domestic recycling activities. Yet again, there is no way to ascertain whether Chinese BOs hold enough vessel volume to sustain operations at domestic SRFs in the future.
4.2. The role of ship recycling for China's Circular Economy

While the above discussion highlighted a hidden potential for sustaining shipbreaking operations in China, the more fundamental question is to which extent ship recycling actually contributes to the national CE. In this regard, quantifying recovered secondary materials and the respectively generated economic value are key indicators for a meaningful evaluation. A closer look at the dimension of both factors however shows that the role of ship dismantling for China's CE has at best been marginal (Table 1). Moreover, in face of the continuously shrinking significance over recent years, we can assume that policy makers may rather be inclined to neglect ship recycling, instead of sustaining it via costly fiscal policy measures. This unfavourable constellation further diminishes the potential of the sector to play a particular role in China's CE in the future.

4.3. The recycling potential of valuable materials reclaimed from EOLS

The previous sections have indicated that there are strong limitations for the CE in ship recycling due to factors pertaining to EOLS supply as well as minimal quantitative and value related contributions to the Chinese CE. Yet, what may possibly be most impairing to the future of EOLS recycling in China is its incompatibility with the particular economic-technical preconditions of the recovery network downstream. Essentially, there are two major impediments: Scrap steel demand and its convertibility for steel production on the one hand and the demand for reuse/recycling of other valuable materials extracted from EOLS.

As for the first aspect, scrap steel has traditionally been attributed with strong environmental benefits in terms of reducing the impact from steel production. Respective assessments by earlier research identified reductions in resource-intensity of around 1,100−1,400 kg of iron ore, 630–740 kg of coal, reductions in energy-use of around 40% and 60–72% in reduced emissions (Wuebbke and Heroth, 2014; Nechifor et al., 2020). These figures provide a particularly strong argument in favour of shipbreaking, which globally represents an important supplier of scrap steel amounting to 3% of the total in 2008 (Rahman and Kim, 2020). In China, however, steel scrap only plays a comparatively small role in crude steel production (11%), compared to the United States (70%) and the EU (56%) (Wuebbke and Heroth, 2014; Nechifor et al., 2020).
2014). Longitudinal data between 2006 and 2012 further shows that scrap utilisation has been decreasing relatively in the overall crude steel production over time (ibidem). Given the low proportion and the overall negligible provision of scrap from EOLS (see Section 4.2) it comes as no surprise that scrap steel provided from ship recycling is not relevant for crude steel producers in China (Hsuan and Parisi, 2020).

A more fundamental issue that technically impairs the volume of scrap steel use as secondary raw material is constituted by China’s steel production infrastructure. Here the technical prevalence is set on the blast furnace to basic oxygen converter route, which accounts for 90% of steel production in the country (Nechifor et al., 2020; Wuebbke and Heroth, 2014). Preference is given to this method as the alternative electric arc furnace uses six times more energy. However, the latter can run entirely on scrap steel, whereas the former converter can only accept a maximum load of 25% scrap (ibidem). Given that the Chinese government has decided to reduce domestic steel production in general (Du et al., 2017), there is little to no probability that the technical limitations for scrap steel use could be offset by an increase in the scale of production.

Apart from steel, the recovery of other reclaimed materials equally faces particular difficulties, which to a significant extent relate to the small market demand for reusable materials from EOLS. According to Hsuan and Parisi (2020), the vast array of second-hand components extracted from obsolete vessels, such as furniture, electrical appliances and various types of equipment, only possess marginal market value. This assessment is confirmed by findings from our survey interviews. One SRF manager from Zhejiang province for example stated that second-hand markets existed in the 1980s when living standards were relatively low in China and spare parts for ships were in high demand. Nowadays, such structures seem to have vanished, as new components tend to be preferred, which only leaves limited space for demand for motors and lifeboats (Interview 5, 2015). However, in other areas, such as in Guangdong province, demand for reusable components from EOLS still existed and came from steel mills and manufacturing (see Table 2). By implication, it must be assumed that second-hand markets for reusable materials such as motors, wires and cables as well as marine equipment exist, yet their significance for recyclers varies on a case-to-case basis. Nevertheless, steel and metal fractions are still most important regarding quantities and value of sales and therefore dwarf the role of other reusable component sales. This in turn underlines the dependency of SRFs on a vibrant metal processing industry, which given the current structural context does at present not exist.

**Table 1**

|                | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|----------------|------|------|------|------|------|------|------|
| [A] Recovered material from EOLS (in million tons) | 4.3  | 5.6  | 2.5  | 1.9  | 1.6  | n.a. | n.a. |
| [B] Overall recovered material in China’s recycling industry (in million tons) | 211.9 | 210.4 | 205.8 | 286.0 | 287.2 | n.a. | n.a. |
| Proportion of [A] to [B] | 2.1% | 2.7% | 1.2% | 0.7% | 0.6% | n.a. | n.a. |
| [C] Value from EOLS recycling (in billion CNY) | 6.31 | 6.38 | 1.14 | 2.18 | 0.75 | 0.86 | 1.49 |
| [D] Value of China’s recycling industry (in billion CNY) | 576.4 | 541.3 | 481.7 | 644.7 | 514.9 | 586.8 | 755.1 |
| Proportion of [C] to [D] | 1.09% | 1.18% | 0.24% | 0.34% | 0.15% | 0.15% | 0.19% |

Note figures shaded grey indicate a conversion of general tonnage into reusable material according to a factor of 0.98 (compare Choi et al., 2016; Yin and Fan, 2018).
against the background of the waste import ban (MEE et al., 2018) and the decline in macro-economic demand for scrap steel (Interview 4, 2015; Interview 5, 2015, NBSE, 2014), China's ship recycling sector is very likely entering a period of contraction, which in the worst case may induce the end of the industry.

Against this background, the options for SRFs to mitigate these challenges are limited. Firstly, there is the possibility to tap into a hidden potential of reflagging foreign-flagged vessels under Chinese BO and thus transfer eventual EOLS to Chinese recyclers. Yet, doing so will not solve the issue of limited scrap demand in the Chinese economy. Moreover, the economic and technical impediments of reusing steel scrap in China are highly limited, which essentially curtails the future sales market potential of scrap steel from SRFs. Similarly, there is only little demand in modern shipbuilding for the reuse of components and appliances that are recovered from obsolete vessels. In final instance, the contribution of the ship recycling sector to the Chinese CE is by and large negligible, which reduces the probability of efforts from policymakers to sustain the sector at high costs. Yet our analysis shows that a shift in SRFs operations, that is from recycling towards reuse and refurbishment of ships, may prove to be a viable way out: This alternative CE segment has thrived in recent years and given China's comparatively large fleet there is indeed a large theoretical demand for repair services. From this perspective, the looming end of ship recycling may simultaneously buttress the rise of another, even more material conserving CE domain.

4.4. Ship repair as alternative circular economic practice to ship recycling in China

The above analysis shows that options for EOLS recycling in China have been largely exhausted with little remaining potential for further promoting or sustaining the industry at its current size. Given this constellation, alternative approaches for a CE management of EOLS need to be chosen from the conceptual domains of repair and refurbishment. This in fact could be good news for the country for two reasons: Not only are such reuse-oriented practices more desirable in the sense of the CE, China moreover possesses substantial capacities for extended ship refurbishment and repair. Recent research highlights that China's fleet ranks third in deadweight tonnage (9.1% of the global market) and first in terms of vessel number (4,966 units) (Yin and Fan, 2018). Given these figures, it comes as no surprise that Chinese yards dominate the global vessel repair industry. A much-noticed survey of 600 international ship repair yards by Clarksons Shipping in 2018 highlighted that 10 of the top 12 yards were situated in China (Chambers, 2019). This is confirmed by an earlier survey, which stated that measured by the number of vessels repaired, China occupied the top three positions in the industry (Offshore energy, 2012). As of now, China's ship repair segment constitutes between 40 and 44% of the global ship repair market (TechSina, 2020; CNSS, 2020).

To SRFs, a structural shift away from ship recycling towards ship repair has been suggested by previous research using the argument of higher profit margins (Du et al., 2017). The potential of this parallel sector has been clearly displayed in recent years when economic performance rose substantially: From 2014 to 2019, overall profits of China's ship repair industry increased from 220 to 600 million CNY (Textor, 2020) as the entire sector grew by 3.7% during the same period (Ibisworld, 2019). This timeline coincides with the parallel downturn of China's ship recycling between 2013 and 2019 (Steuer et al., 2020) and the sudden productivity increase of 41.5% in the first half of 2019 in the ship repair segment (CSIBA, 2020) provides further testimony to this synchronicity in sectoral developments. Interestingly, our survey amongst SRFs has shown that some yards responded to the challenges in the recycling market by diversifying their operations towards repair and refurbishment services (Steuer et al., 2020). However preliminary in nature, it seems that an operational shift in this direction can enable the continuation of CE treatment practices for EOLS in China.

5. Conclusion

The analysis in the above sections highlight an interesting paradox in the context of China's CE. On the one hand, there are ship recyclers, which at least based on the insights from our limited yard sample size appear to perform comparatively sustainable (compare Jain, 2017). Not only did SRFs take stringent measures to prevent pollutant emissions and protect worker safety. The high degree of material recovery (99% of dismantled LDT) further underscores the strong CE potential of China's ship recycling sector. While our findings only cover a limited size of the entire sector and despite minor incidences of uncontrolled emission leakages, when compared to other countries (see Jain, 2017) China's SRFs yet perform relatively sustainable. On the other hand, against the background of the waste import ban (MEE et al., 2018) and the decline in macro-economic demand for scrap steel (Interview 4, 2015; Interview 5, 2015, NBSE, 2014), China's ship recycling sector is very likely entering a period of contraction, which in the worst case may induce the end of the industry.

Against this background, the options for SRFs to mitigate these challenges are limited. Firstly, there is the possibility to tap into a hidden potential of reflagging foreign-flagged vessels under Chinese BO and thus transfer eventual EOLS to Chinese recyclers. Yet, doing so will not solve the issue of limited scrap demand in the Chinese economy. Moreover, the economic and technical impediments of reusing steel scrap in China are highly limited, which essentially curtails the future sales market potential of scrap steel from SRFs. Similarly, there is only little demand in modern shipbuilding for the reuse of components and appliances that are recovered from obsolete vessels. In final instance, the contribution of the ship recycling sector to the Chinese CE is by and large negligible, which reduces the probability of efforts from policymakers to sustain the sector at high costs. Yet our analysis shows that a shift in SRFs operations, that is from recycling towards reuse and refurbishment of ships, may prove to be a viable way out: This alternative CE segment has thrived in recent years and given China's comparatively large fleet there is indeed a large theoretical demand for repair services. From this perspective, the looming end of ship recycling may simultaneously buttress the rise of another, even more material conserving CE domain.

Declaration of Competing Interest

The authors hereby state that there is no conflict of interest concerning the publication of this article.

Acknowledgements

Research for this article resulted from the EU-China project “Sustainable Ship Recycling by Adopting Integrated Waste Management Approaches in China” (2013–2016) (Grant Contract: DCI-ASIE/2013/322-333). The project resulted from a cooperation between the Institute of Waste Management at the University of Natural Resources and Life Sciences, Vienna (ABF-BOKU), the Beijing University of Civil Engineering and Architecture (BUCEA), the National Solid Waste Management Centre of China (NSWMC – Ministry of Environmental Protection) and the China Association of Resource Comprehensive Utilization (CARCU). ABF-BOKU led the field surveys and interviews, whereas NSWMC and CARCU were responsible for the MFA data gathering. The project itself was funded by the EU-China Environmental Sustainability Programme (ESP). Particular gratitude goes to two anonymous reviewers for their valuable comments and suggestions.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2020.105039.
References

Alam, S., Faruque, A., 2014. Legal regulation of the shipbreaking industry in Bangladesh: the international regulatory framework and domestic implementation challenges. Mar. Policy 47, 46–56. http://dx.doi.org/10.1016/j.marpol.2014.01.022.

BJX (North Star Solid Waste Web), 2019. Review of the situation on overall recycled quantities in China's recycling industry and an interpretation of the comprehensive statistics of China's recovered metal resources (in Chinese). Online: http://buanbao.bjx.com.cn/news/20190703/990240.shtml.

Chambers, S.2019. Chinese yards dominate the repair industry. Online:https://splash247.com/chinese-yards-dominate-repair-industry/.

Choi, J., Kelley, D., Murphy, S., Thangamani, D., 2016. Economic and environmental perspectives of end-of-life shipmanagement. Resour. Conserv. Recycl. 107, 82–91. http://dx.doi.org/10.1016/j.resconrec.2015.12.007.

CSIBA (China Ship Industry Business Association), 2020. China's ship repair industry grew stable in the first half year and ship repair increased by 41.5% (in Chinese). Online:http://www.bjx.com.cn/news/20190703/990240.shtml.

Du, Z., Zhu, H., Zhou, Q., Wong, Y.D., 2017. Challenges and solutions for ship recycling in China. Ocean Eng. 137, 429–439. http://dx.doi.org/10.1016/j.oceaneng.2017.04.004.

Eworldship, 2017. China State Shipbuilding Corporation Limited. Situation analysis on the economic operations of the ship recycling industry during the first nine months (in Chinese). Online: http://www.eeworldship.com/html/2017/133007.html.

Hiremath, A.M., Pandey, S.K., Asolekar, S.R., 2016. Economic and environmental perspectives of end-of-life management in ship recycling yards. Resour. Conserv. Recycl. 107, 82–91. http://dx.doi.org/10.1016/j.resconrec.2015.12.007.

CNSS, 2020. China’s ship repair industry: adapting to change and looking for opportunities to break through the epidemic. Online:https://www.cnss.com.cn/html/bysc/20200624/335557.html.

CNSRA, 2017. China National Ship Recycling Association. Notice on the 13th 5yp for the development of the ship breaking industry (in Chinese). Document No. 8/2017.

CSIRA (China Ship Industry Business Association), 2020. China’s ship repair industry grew stable in the first half year and ship repair increased by 41.5% (in Chinese). Online:http://www.gongyetoutiao.com/xw/html/17145.shtml.

Chambers, S.2019. Chinese yards dominate the repair industry. Online: https://splash247.com/chinese-yards-dominate-repair-industry/.

Choi, J., Kelley, D., Murphy, S., Thangamani, D., 2016. Economic and environmental perspectives of end-of-life shipmanagement. Resour. Conserv. Recycl. 107, 82–91. http://dx.doi.org/10.1016/j.resconrec.2015.12.007.

Du, Z., Zhu, H., Zhou, Q., Wong, Y.D., 2017. Challenges and solutions for ship recycling in China. Ocean Eng. 137, 429–439. http://dx.doi.org/10.1016/j.oceaneng.2017.04.004.

Eworldship, 2017. China State Shipbuilding Corporation Limited. Situation analysis on the economic operations of the ship recycling industry during the first nine months (in Chinese). Online: http://www.eeworldship.com/html/2017/133007.html.

Hiremath, A.M., Pandey, S.K., Asolekar, S.R., 2016. Development of ship-specific recycling plan to improve health safety and environment in ship recycling yards. J. Clean. Prod. 116, 279–288. http://dx.doi.org/10.1016/j.jclepro.2016.01.006.

Huan, J., Parisi, C., 2020. Mapping the supply chain of ship recycling. Mar. Policy 118. http://dx.doi.org/10.1016/j.marpol.2020.103979.

Ibistradeworld, 2019. Ship repairing and Conversion in China – industry trends 2015-2020. Online:https://www.ibistradeworld.com/china/market-research-reports/ship-repairing-conversion-industry/.

Interview 1, 2014. Tan Yang President General Manager of Jiangmen Xinhai Shangshuai Shipbreaking & Steel. Co., Ltd.Tan Yang President General Manager of Jiangmen Xinhai Shangshuai Shipbreaking & Steel. Co., Ltd.

Interview 2, 2014. Liang Zhouruan General Manager of Jiangmen Zhongxin Shipbreaking & Steel Co., Ltd.

Interview 3, 2014.Lin Yuquan Assistant General Manager of Jiangmen Yinhua Shipbreaking Co., Ltd.

Interview 4, 2014.Jimmy Hao Assistant General Manager Jiangyin Changjiang Ship Recycling.

Interview 5, 2014.Mr Huang Yafeng Vice Manager of Zhou Shan Chang Hong International Shipyard Co., Ltd.

Interview 6, 2015. Mr Zhang Junchao General Manager of Zhejiang Hongying Shipbreaking Co.,Ltd.

Jain, K.P., 2017. Improving the Competitiveness of Green Ship Recycling. pp. 1–211.

Ma, H., et al., 2014. Best Practice Report of Ship Dismantling in China. pp. 1–18 Internal Project report.

Mikelis, N.E., 2013. Ship recycling markets and the impact of the Hong Kong convention. In: SHIPREC 2013 – International Conference on Ship Recycling. Malmo. World Maritime University 7-9 April 2013.

Ministry of Ecology and Environment (MEE) and others. 2018. Announcement on adjustment to the catalogue for the administration of import solid waste. Announcement No. 6 - 2018. Online:https://images.magnetmail.net/2018/08/15/ISRIID/attach/MEEAnnouncement20180213Banisheditems.pdf.

NBSE, 2014. The ship recycling industry has a steeled plan: not to push dismantling (in Chinese). Online:http://nbse.net.cn/Publish/2015/1/3776d95006921e3a95700c29d4e3e3eh.html.

Nechifor, V., Calzadilla, A., Bleischwitz, R., Winning, M., Tian, X., Usubiaga, A., 2020. Steel in a circular economy: global implications of a green shift in China. World Dev. 127. https://doi.org/10.1016/j.worlddev.2019.104775.

NGO Shipbreaking Platform (2014-2019). Annual lists of scrapped ships 2014-2019. Online:www.shipbreakingplatform.org/resources/annual-lists.

Offshore Energy, 2012. Chinese ship repair enterprises hold top three positions in the industry. Online:https://www.offshore-energy.biz/chinese-ship-repair-enterprises-hold-top-three-positions-in-the-industry.

Rahman, S.M.M., Handler, R.M., Mayer, A.L., 2016. Life cycle assessment of steel in the ship recycling industry in Bangladesh. J. Clean. Prod. 135, 963–971. http://dx.doi.org/10.1016/j.jclepro.2016.07.014.

Rahman, S.M.M., Kim, J., 2020. Circular economy, proximity, and shipbreaking: a material flow and environmental impact analysis. J. Clean. Prod. 259, 1–11. https://doi.org/10.1016/j.jclepro.2020.120681.

Steuer, B., Staudner, M., Ramusch, R., 2020. Economic distress and regulatory inconsistency: the decline of ship recycling in China. J. Environ. Manag (submitted for review).

Tech Sina, 2020. Adjusting the policy on foreign ship repair and waste steel disposal (in Chinese). Online:https://tech.sina.com.cn/roll/2020-05-23/doc-iirczymk3082796.shtml.

Textor, C.2020. Profits of the ship repair industry in China 2014-2019. Online:https://www.statista.com/statistics/1064608/china-ship-repair-industry-profits/.

Wuebbke, J., Heroth, T., 2014. Challenges and political solutions for steel recycling in China. Resour. Conserv. Recycl. 87, 1–7. http://dx.doi.org/10.1016/j.resconrec.2014.03.004.

Yin, J., Pan, L., 2018. Survival analysis of the world ship demolition market. Transp. Policy 63, 141–156. https://doi.org/10.1016/j.tranpol.2017.12.019.

Zhao, Y., Chang, Y., 2014. A comparison of ship-recycling legislation between Chinese law and the 2009 Hong Kong convention. Ocean Dev. Int. Law 45 (1), 53–66. http://dx.doi.org/10.1080/00908320.2013.839157.

Resources, Conservation & Recycling 164 (2021) 105039