ADB

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Maldives: Greater Male Environmental Improvement and Waste Management Project - Market Study on the Reuse of Incinerator Bottom Ash and Construction and Demolition Waste in the Maldives

Asian Development Bank

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ABBREVIATIONS

ADB	Asian Development Bank
CDW	Construction Demolition Waste
CIF	Cost, Insurance and Freight
IBA	Incinerator Bottom Ash
IBA (r-IBA)	Recycled Incinerator Bottom Ash
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incinerator
SWM	Solid Waste Management
tpd	Tons per day
WTE	Waste-to-Energy
TA	Technical Assistance
RCA	Recycled Concrete Aggregates
RC	Recycled Aggregates
STO	State Trading Organization

1. Project

1.1. Project Description

Greater Male' is centrally located in Maldives and is the capital city of the nation. The Male' island and its 32 inhabited islands are categorized as Zone 3 in the National Solid Waste Management Policy. Greater Male' Region lack a proper waste management system. For the last 30 years, waste has been collected, transferred by sea, dumped and burnt at an open dump site at Thilafushi, an island 6km away from Male'. The current practice of waste management poses an environmental and public safety issue. Some waste, often in plastic bags, are lost to the sea during transportation and toxic leachate from the Thilafushi dump site contaminate the ground water. The smoke from burning of waste causes air pollution. The current practice of waste management is not sustainable.

The Greater Male' region (Zone 3) produces 774 tons per day (tpd) of mixed solid waste. The breakdown of waste is given in Table 1 and Table 2 shows the composition of Municipal Solid Waste (MSW). Due to the rapid urbanization and tourism development in Zone 3, it is expected the waste generation would increase to 924 tpd by 2022.

Table 1. Breakdown of Waste by Type

Type	**Amount** (tons per day)	
Construction Demolition Waste	530	68%
Household	149	19%
Resort	48	6%
Commercial	27	3%
Airport	9.3	1.2%
Industrial	6	0.8%
Market	2.5	0.3%
Hazardous	1.5	0.2%
End-of-life vehicles	0.65	0.1%

Table 2. Composition of Municipal Solid Waste

Type of Municipal Solid Waste	
Organic	53%
Paper and cardboard	12%
Plastic	11%
Hazardous (medical)	8%
Metal	3%
Glass	3%
Others	11%

As an alternative to the current unsustainable practice of burning mixed solid waste, Greater Male' Environmental Improvement and Waste Management Project (Project), supported by the Asian Development Bank (ADB), is going to strengthen the solid waste management (SWM) in Zone 3. The Project will establish an integrated SWM system including collection, transfer, treatment using advanced waste-to-energy (WTE) technology, disposal, recycling, dumpsite closure and remediation, public awareness in reduce-reuse-recycle (3R), and strengthening institutional capacities for service delivery and environmental monitoring. The Government will implement the Project in two phases;

Phase 1 includes Construction Demolition Waste (CDW) processing facility (200 tpd capacity).

Phase 2 will consist of a WTE incineration of 500 tpd of Municipal Solid Waste (MSW) and the flammable fraction of the CDW

The incineration process reduces the waste to energy, Incinerator Bottom Ash (IBA) and fly ash. The fly ash will be disposed in a landfill. The IBA can also be disposed in a landfill. However, it is expected 100 to 125 tpd of IBA would be generated and land scarcity in Zone 3 limits the disposal of IBA in landfills. Alternatively, IBA could be treated further to produce recycled IBA (r-IBA) and reused as a building material.

CDW is mixed waste generated from construction and demolition activities. Soil and sand is not considered as CDW in this report as it is usually reused as backfill material. Disposal of CDW in landfills is also challenging due to land scarcity. CDW can be processed as recycled aggregates that could be used in various applications in the construction industry.

1.2. Objective of Technical Assistance

The objective of this assignment is to assess the potential market for IBA and CDW reuse in the Maldives.

1.3. Scope of Technical Assistance

The scope of this Technical Assistance (TA) is to conduct a market assessment for potential IBA and CDW reuse in the Maldives. Current use of aggregates with the aim of identifying potential applications, required national standards, costs, and current and projected demand for recycled IBA and CDW in the Maldives is analyzed. Detailed tasks of this assignment include:

(i) Identify suitable applications for treated IBA and CDW reuse in the Maldives through literature review and surveys.

(ii) Review applicable national standards for the reuse of treated IBA and CDW for the potential applications as identified in (i) and summarize the required material characteristics (e.g. chemical, physical).

(iii) Conduct interviews/surveys with key stakeholders to understand their views on potential reuse, product requirements, and willingness to pay for treated IBA and CDW.

(iv) Collect information on cost and demand of similar construction materials (to IBA and CDW) currently used in the Maldives.

(v) Conduct a market demand analysis for reusing treated IBA and CDW in the Maldives including projections for next 5, 10 and 15 years

(vi) Recommend possible ways/alternatives for maximize IBA and CDW demand/reuse and sustainable business models for the Greater Male context.

(vii) Prepare comprehensive report on the activities (i) to (vi) with key recommendations for IBA treatment and CDW plant design and operation

2. Suitable Applications for Incinerator Bottom Ash

Incineration of MSW releases the energy during combustion. The waste reduces in weight by about 70%. IBA accounts for about 80% of the incombustible residue left [1]. The remaining of the residue is fly ash. Incombustible metals, glasses, ceramics, slag and sand mixture form as IBA and is rich in heavy metals, chlorides, oxides and organic pollutants. IBA require removal of ferrous and non-ferrous metals and further treatment to enhance its reusability. The type of treatment process adopted affects the leaching property and consequently the reusability of r-IBA. Common oxides and heavy metals found in IBA are given in Table 3. The composition of the oxides and heavy metals depend on the characteristics of the MSW but SiO_2 is generally the most abundant oxide in IBA[2].

IBA is similar in its size and appearance to aggregates and hence can be used as a substitute to aggregates in applications aggregates are required. The main factors affecting the reuse of IBA is the suitability of IBA for treatment and processing, the

[1] Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.
[2] Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

attainability of required properties for a given application, and the environmental impact from the reuse of IBA [3].

Reuse of IBA has been studied for the past 40 years. Lynn, Dhir, & Ghataora (2016) studied 76 publications published since 1979 over 18 countries[4] (Figure 1). Reuse of IBA is most prevalent in Europe. In Asia, reuse of IBA is prevalent in countries like Taiwan, Singapore and Japan where land is scarce.

Table 3. Oxides and heavy metals in incinerator bottom ash[2]

Oxides		**Heavy Metals**	
SiO_2	K_2O	Ag	Mn
Al_2O_3	Na_2O	As	Ni
CaO	SO_3	Ba	Pb
Fe_2O_3	P_2O_5	Cd	Se
MgO	TiO_2	Co	Zn
		Cr	Sn
		Cu	Sr
		Hg	V

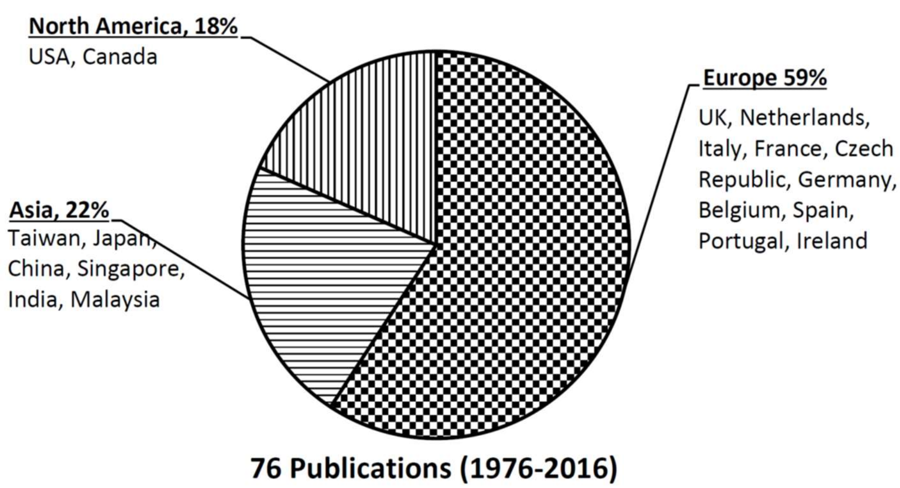

Figure 1.Global distribution of publications on MIBA in concrete applications[4]

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[3] Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

[4] Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

There are two main literature that had collected the fragmented studies done and reviewed them in a single work. The work of Lam, Ip, Barford, and McKay[5] categorized the utilization of IBA and fly ash into seven different applications; cement and concrete production, road construction, glasses and ceramics, agriculture, stabilizing agent, adsorbents and zeolite production. Incinerator fly ash is utilized as a stabilizing agent and in zeolite production. Since the scope of this TA is only IBA, applications for incinerator fly ash will not be discussed. Lynn, Dhir, & Ghataora, (2016) had reviewed 76 publications and focused the work on the reuse of IBA as aggregates in concrete applications[6]. Additionally, there is literature that support the utilization of IBA in land reclamation works in Singapore and Japan. The utilization of r-IBA as raw materials in glass, ceramic and blasting grit production is supported by studies[5]. However, there is no glass and ceramic production industry in Maldives and hence reuse of r-IBA for glass and ceramic production is not a practical application in Maldives.

Existing literature was reviewed and the following utilizations of r-IBA are evaluated to determine their potential in Maldives.

i. Cement manufacturing
ii. Concrete production
iii. Masonry and pavement block production
iv. Road construction
v. Land reclamation
vi. Coastal protection systems

[5] Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

[6] Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

2.1. Cement Manufacturing

Calcareous materials like limestone and argillaceous materials like shale and clay are raw materials for cement production. These raw materials provide the reactants CaO, SiO_2, Fe_2O_3 and Al_2O_3 required for cement production. These oxides are also present in IBA (Table 3). Hence, IBA can be used as a substitute raw material in cement manufacturing[7]. However, corrosion of the cement kiln due to chloride ions and heavy metals in IBA can limit its reusability in cement manufacturing. Treatment of IBA is essential to reduce the effects of chloride and heavy metals. Pan, Huang, Kuo, and Lin used the washing treatment process and the cement produced conformed to the Chinese National Standards of Type II cement [8], suggesting the technical feasibility of utilizing treated IBA in cement production.

Maldives does not have a cement manufacturing industry. However, exporting the treated IBA to a cement manufacturer in an Asia is a possible option that could be explored. The requirements of Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal should be met for exporting the treated IBA.

2.2. Concrete Production

Treated IBA can be used as coarse aggregates and fine aggregates in concrete. The physical characteristics of IBA is an important factor that defines the properties of concrete made using IBA.

One of the physical properties of IBA that influence other physical properties of IBA and consequently the properties of concrete made with treated IBA is porosity. The porosity of IBA is higher than that of natural aggregates. Consequently, the absorption of IBA is

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[7] Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

[8] Pan, J. R., Huang, C., Kuo, J.-J., & Lin, S.-H. (2008). Recycling MSWI bottom and fly ash as raw materials for Portland cement. *Waste Management*, 1113-1118.

higher. An averaged value of the water absorption is 9.7% and ranges over 2.4 – 15.0 %[9]. The porosity and absorption influence the bond between the cement paste and IBA. Aggregates are used as a fill material for concrete and can take up three quarters of the volume of concrete. Hence the high porosity and absorption of IBA used in concrete increases the porosity and absorption of the hardened concrete.

The high porosity of IBA contributes to the low specific gravity of IBA. The average specific density of IBA is 2.32[8]. This is comparably less than the typical specific density of natural aggregates. The specific density of natural aggregates is between 2.6 and 2.7[10]. The specific density depends on the treatment process as well.

Table 4 summarizes Lynn, Dhir, and Ghataora's review of the 76 publications focusing on the reuse of IBA in concrete[9]. As observed from Table 4, the performance of concrete produced with IBA is lower than concrete with natural aggregates. The workability is reduced due to high absorption of IBA. The compressive strength and tensile strength is lower. The current construction practices are very traditional in Maldives. It is a common practice to add water on site to the concrete mix to improve the workability. However, uncontrolled addition of water can further reduce the compressive strength of concrete. A reduction in compressive strength is translated to a reduction in flexural tensile strength of concrete. Concrete with lower tensile strength is susceptible to early cracking. Furthermore, the presence of chloride ions in IBA with close proximity to the reinforcing steel increases the risk of reduced durability. The existing literature lack a focus on long-term durability.

The practical utilization of IBA in concrete applications is in the early stages[9]. Due to the poor performance of concrete with IBA as aggregates, unreliable workmanship and the associated risks and lack of long-term durability studies, the reuse of r-IBA in structural concrete applications in Maldives is not recommended.

[9] Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.
[10] Neville, A. M., & Brooks, J. J. (2010). *Concrete Technology.* Harlow: Pearson Education Limited.

Table 4. Effect on properties of concrete when r-IBA replaced natural aggregates

Property of Concrete	**Change in property when aggregates replaced with IBA**
Slump	Reduces
Cohesiveness	Remains cohesive
Segregation	No segregation
Bleeding	Bleeding reduces
Setting time	Increases
Compressive strength	Decreases
Tensile strength	Decreases
Elastic modulus	Decreases
Shrinkage	Increases
Creep	No significant change
Absorption	Increases
Chloride corrosion	Higher risk
Sulfate attack	No expansion due to sulfate attack
Carbonation resistance	Carbonation depth decreases

2.3. Masonry and Pavement Block Production

Concrete masonry blocks are extensively used in the construction industry. They are mainly used in non-load bearing masonry walls. Concrete masonry blocks used for majority of projects are locally produced. Sand quarried from lagoons are used as fine aggregates in block production. Use of local quarried sand is not a sustainable use of natural resources. Furthermore, the chloride content of the blocks due to the sand quarried from the sea floor can be high. However, supply of local quarried sand is limited and hence some large-scale block producers depend on imported sand.

The unit weight of masonry blocks with IBA is less than normal masonry blocks. This is due to the lower specific gravity of IBA. Since, the absorption of IBA is higher, the water demand during production is higher. The compressive strength of masonry and pavement blocks with IBA is lower. However, since the strength demanded from masonry products is lower, the target strength is achieved in non-load bearing, load bearing, paving and interlocking blocks[11]. Fire resistance performance is comparable to the products made with natural aggregates and no adverse shrinkage cracking is observed when IBA is used as a fine aggregate. Additionally, concrete paving blocks made with IBA exhibited excellent slip resistance and can be classified as having low potential for slip as per BS EN 1333[11].

Furthermore, full-scale operations had been conducted with masonry and pavement blocks made with IBA. There has been reports of spalling in projects carried out in the nineties. This is due to corrosion of the ferrous metal in IBA. However, with advanced treatment methods, the problem of spalling can be easily resolved. Most of the full-scale operations can be deemed successful[11].

Quality of masonry and pavement blocks made with IBA as aggregates is slightly inferior to similar products with natural aggregates. However, the requirements of masonry and pavement products is less than those of structural concrete. Therefore, review of literature suggests that the performance of the products with IBA can be of acceptable standards[11.]

Concrete masonry blocks are extensively used in non-structural applications in Maldives and the reuse of r-IBA is a more sustainable use of materials than the current use of chloride rich quarried sand. Therefore, utilization of r-IBA in concrete masonry and pavement block production has high potential in Maldives.

2.4. Road Construction

Reuse of IBA in road construction is one of the applications where IBA is utilized most in Europe. The research of IBA utilization in road construction is well progressed and

[11] Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

translated to field applications in countries like Belgium, Denmark, Germany and Netherlands[12].

A typical road cross-section has the wearing course as top surface, the base course and then the sub-base layer. Interlocking concrete blocks has been mostly used for the wearing course layer in Maldives though the use of bituminous asphalt in new roads is increasing. The sub-base layer is constructed on the subgrade, compacted natural soil as the foundation for the road. The base course and the sub-base is constructed with graded aggregates. Treated IBA can replace the natural aggregates used for the base course and sub-base layer[12]. IBA can be used in unbound form, hydraulically bound or bitumen bound form.

Hydraulically bound IBA is often stabilized with cement or lime when used in base layers. Singh and Kumar studied the geotechnical properties of MSWI ash mixed with cement[13]. The particle sizes of the MSWI ash used by Singh, et.al ranges from 75 microns to 1.18mm and suggests the study used IBA. Singh, et.al found that the California Bearing Ratio (CBR) value, Unconfined Compressive Strength (UCS) and Split Tensile Strength (STS) of MSWI increases when mixed with cement and suggests the MSWI mixed with cement can be used as an alternative material for road bases. However, the study of Singh, et.al did not focus on the environmental impacts of MSWI when used in ground works. A similar study in China also indicate the IBA mixed with cement satisfy the strength requirements for use on base and sub-base layers of heavy highway traffic[14]. However, the use of cement can increase the cost of the road construction.

Lynn, Ghataora, and Dhir had done an evaluation of the global experimental data on the use of IBA in road construction[15]. The analysis confirms that unbound IBA meets the grading requirement after standard processing and can be compacted well with

[12] Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

[13] Singh, D., & Kumar, A. (2017). Geo-environmental application of municipal solid waste incinerator ash stabilized with cement. *Journal of Rock Mechanics and Geotechnical Engineering*, 370-375.

[14] Tang, Q., Gu, F., Chen, H., Lu, C., & Zhang, Y. (2018). Mechanical Evaluation of Bottom Ash from Municipal Solid Waste Incineration Used in Roadbase. *Advances in Civil Engineering*.

[15] Lynn, C. J., Ghataora, G. S., & Dhir, R. K. (2017). Municipal incinerated bottom ash (MIBA) characteristics and potential for use in road pavements. *International Journal of Pavement Research and Technology*, 185-201.

performance similar to that of sandy gravel. Unbound IBA meets the requirements of a material suitable for sub-base and is widely used in Denmark and Netherlands. IBA bound with a stabilizing agent like cement or lime can be processed to satisfy the requirements of a sub-base or base-course material by adjusting the binder content. Laboratory results of hydraulically bound IBA shows low density and elastic modulus. However, performance measured in full-scale projects suggests hydraulically bound IBA can be satisfactorily used despite lower laboratory results. Additionally, there are full-scale projects that provides evidence that low contents of IBA can be used to form bituminous bound bases and wearing course layers.

Environmental impact of the IBA used in road construction is as important as the mechanical properties. Lynn, Ghataora, and Dhir, had done an evaluation of global literature published on the environmental impacts of IBA as a road construction material[16]. Lynn, Ghataora, and Dhir's analysis concluded that IBA in unbound form poses the highest risk of leaching heavy metals and contaminants to the ground water but the risk could be minimized by treatment prior to utilization[16]. However, IBA bound with cement or bitumen restricts the leaching and the leachate concentrations were below the utilization and water quality limits. Therefore, the environmental impacts of the reuse of IBA in road construction does not limit its utilization.

Roads in most islands in Maldives are not leveled and paved. Only the capital city Male', Hulhumale' and Villimale' have all the roads paved, either with interlocking concrete paving blocks or asphalt. Some of the larger islands like Laamu Atoll Gan, Seenu Atoll Gan and Fuvahmulah have the main road paved with asphalt. The islands without paved roads create an opportunity for the reuse of IBA. Currently, there are eight road development projects in eight different islands in the tender phase. Similarly, future airport developments are potential applications for the utilization of IBA. However, according to Regional Airports there are no long-term development plans and the recent increase in new airports was politically rationalized.

[16] Lynn, C. J., Ghataora, G. S., & Dhir, R. K. (2018). Environmental impacts of MIBA in geotechnics and road applications. *Environmental Geotechnics*, 31-55.

2.5. Land Reclamation

The utilization of IBA in land reclamation is published in literature. However, this application is only limited to countries like Singapore and Japan where land is scarce.

In Singapore, IBA and marine clay originating from excavation works are solid wastes. It was proposed to use a mixture of stabilized IBA and marine clay as a fill material for land reclamation[17]. The mechanical properties and environmental impact assessments were tested. The literature concluded the reuse of IBA and marine clay matrix is feasible from both geotechnical and environmental perspective[18]. However, it should be highlighted that the polymer-based cementious stabilizer Chemlink SS-331H is a proprietary product.

In Japan, approximately 78% of MSW that is disposed in coastal landfill sites is MSWI ash and 20% of the MSW is disposed in coastal landfills, mostly located in port areas of Tokyo, Nagoya and Osaka[19]. Various studies had showed the geotechnical properties of the landfills improved. Nguyen, Inui, Ikeda, and Katsumi had taken waste mixture samples just before being disposed at coastal landfill site in Osaka Bay area and studied the time dependent geotechnical properties of waste mixtures submerged in landfill leachate or seawater. The composition of the waste mixture was approximately 50% of MSWI ash, 30% of gravel materials like slags, and 20% surplus soil. The study concluded that the shear strength increases and deformation decreases with time and hence waste mixture layers studied could be used as foundation layers with adequate bearing capacity after closure of the coastal landfill sites[20].

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[17] Guo, L., & Wu, D. -Q. (2018). Study of leaching scenarios for the application of incineration bottom ash and marine clay for land reclamation. *Sustainable Environment Research*, 396-402.

[18] Guo, L., & Wu, D.-Q. (2017). Study of recycling Singapore solid waste as land reclamation filling material. *Sustainable Environment Research*, 1-6.

[19] Nguyen, L. C., Inui, T., Ikeda, K., & Katsumi, T. (2015). Aging effects on the mechanical property of waste mixture in coastal landfill sites. *Soils andFoundations*, 1441-1453.

[20] Nguyen, L. C., Inui, T., Ikeda, K., & Katsumi, T. (2015). Aging effects on the mechanical property of waste mixture in coastal landfill sites. *Soils andFoundations*, 1441-1453.

Land reclamation activities had rapidly increased over the last five years with several islands being reclaimed as a solution to land scarcity. Sand for reclamation is quarried from borrow sites in lagoons.

The reuse of IBA as a landfill material can be a potential alternative to the use of natural sand dredged from the lagoons. However, large quantities of sediments are required for some land reclamation projects and IBA generated might not be adequate for a single project. However, there is the opportunity for blending stabilized IBA with natural sediments during land reclamation. Further research is required to support the reuse of IBA as a blended material in land reclamation.

The duration and frequency of land reclamation is different to IBA generation. Frequency of reclamation projects are discrete and the duration is relatively shorter compared to the large volume of sediments mobilized. However, IBA generation is more continuous and subjected to maturation period as well. If r-IBA is planned to use, large volumes of IBA might be required to be stored for a long period of time. Therefore, even though the reuse of IBA in land reclamation or land filling might be a technically potential application, there might be operational limitations.

2.6. Coastal protection systems

Maldives being a coastal country, reuse of IBA in coastal protection systems can be a potential application. However, literature review revealed that the reuse of IBA in coastal protection systems is an area where there is a gap in literature.

One of the applications for reuse of IBA can be in concrete for quay walls and jetties. However, these are structural applications and due to inadequate performance of concrete with IBA, reuse of IBA in construction of quay walls and jetties is not recommended.

Crushed rocks are commonly used as revetments and breakwaters in Maldives. Alternatively, tetrapods made from concrete can be used and since it is not a structural application IBA can be used as aggregates in tetrapod production. However, durability is a concern and require further research to fully validate this application. A solution to ensure durability can be to design a tetrapod with an inner core made of compacted and hydraulically bound IBA and a more durable shell made of concrete with natural aggregates.

An alternative to tetrapod could be geo-bags. Currently sand, often sourced close to the project site is used as a fill material. Since, IBA can be used in road base layers with acceptable leachate performances, stabilized IBA can potentially be used as a fill material for geo-bags. However, this application is subjected to further research and the intermittent frequency of coastal protection projections should be considered.

3. Suitable Applications for Construction Demolition Waste

Recycling of CDW is practiced widely in some countries. In some countries, approximately 90% of the CDW are recycled[21]. BS 8500 (2002) defines two types of aggregates; Recycled Concrete Aggregates (RCA) and Recycled Aggregates (RC). RCA should have minimum 95% crushed concrete and RC is defined as 100% masonry based crushed aggregates. The quality of both types of CDW aggregates is poor compared to natural aggregates. This is primarily due to the mortar adhered to the natural aggregates. The production method influence the quality and composition of CDW aggregates.

Acceptability of CDW aggregates depends on the properties of fresh and hardened concrete incorporating CDW aggregates more than the properties of CDW aggregates itself. Table 5 summarizes the properties of fresh and hardened concrete with CDW aggregates compared to concrete with natural aggregates. As observed from Table 5 the properties of concrete with CDW aggregates is lower than conventional concrete. However, Brito and Saikia had proved that when the partial replacement ratio is less than 30%, the properties of CDW incorporated concrete is comparable to that of conventional concrete and both normal and high-strength concrete could be prepared using CDW aggregates[21]. Furthermore, Brito and Saikia claim that properties of concrete with CDW aggregates could be improved through the mix design[21].

Compared to IBA, CDW aggregates has more potential for reuse in structural concrete in Maldives. The majority of buildings have a concrete frame as the structural form and quay walls and jetties are made of concrete as well. RCA can be used to produce structural concrete and RC can be incorporated into concrete masonry block making. However, since construction of most residential buildings follow traditional methods and concrete is mostly batched volumetrically on site, the risk is high for the reuse of CDW as aggregates in concrete of residential buildings. The risk can be reduced when concrete mixes are designed and tested and batched using a batching plant. Currently, there are very few

[21] Brito, J. d., & Saikia, N. (2013). *Recycled Aggregate: Use of Industrial, Construction and Demolition Waste.* London: Springer

ready-mix concrete producers. Additionally, many old buildings that are being demolished had used sand quarried from lagoons and coral fragments as aggregates. Consequently, the concrete is rich in chloride ions and had caused severe corrosion in old buildings and is one of the main reasons for demolition. Hence, reuse of aggregates made from old buildings constructed using coral fragments would lead to corrosion and would not be accepted by consultants in the industry. Therefore, CDW aggregates should be used in Maldives with caution.

Table 5. Effect on properties of concrete when CDW replaced natural aggregates

Property of Concrete	**Change in property when aggregates replaced with IBA**
Workability	Reduces
Density	Lower
Air-content	Increases
Bleeding	Reduces
Compressive strength	Lower
Split tensile strength	Lower
Flexural strength	Lower
Modulus of Elasticity	Lower
Creep	Increases
Drying shrinkage	Increases
Water absorption	Increases
Chloride permeability	Increases

4. Review of national standards and required material characteristics

Construction Act of 2017 (Act No. 4/2017) and Environment Protection and Preservation Act of 1993 (Act No. 4/93) are the two legislations that could be related to IBA and CDW.

Environment Protection and Preservation Act confers power on a ministry responsible for environment to formulate policies and regulations. Environment Protection and Preservation Act briefly states in clause 7 and 8 that waste, oil and toxic material should be disposed in areas designated by the government, should not damage the environment and if waste burning is adopted it should not harm human health. Ministry of Environment has formulated a National Solid Waste Management Policy in 2008 and revised it in 2015. Ministry of Environment has also issued a Waste Management Regulation (Regulation No. 2013/R-58). Consultation with relevant staff of Ministry of Environment revealed that there are no specific environmental national standards related to IBA and CDW. However, clause 3.1 of Annex 1 of Waste Management Regulation states that International standards should be referred to in cases where there are no national standards. There are no universal standards. Standards differ in each country and reflect factors unique to the specific country. Table 7 shows European Union's minimum waste acceptance criteria for the different categories of waste[22].

Construction Act sets the general principles and confers the power on the ministry to issue regulations to control production, import, testing and use of construction materials. However, currently there are no regulations formulated. Material testing and ensuring compliance to specifications is not widely practiced in Maldives. In circumstance where testing is conducted, only the grading of aggregates and compressive strength of concrete and sometimes masonry blocks is tested. However, when used in non-load bearing walls compressive strength of blocks is not critical. There is no specific standard followed by all the professionals in the construction industry. Some of the standards

[22] Liu, A., Lin, W. Y., & Wang, J. Y. (2015). A review of municipal solid waste environmental standards with a focus on incinerator residues. *International Journal of Sustainable Built Environment*, 165–188.

followed include Australian Standards, British Standards, Indian Standards and standards of American Society for Testing and Materials (ASTM). There are no specific national standards on IBA or CDW. The grading requirements often followed in Maldives is given in Table 6.

Table 6. BS 882:1992 grading requirement for fine aggregates

Sieve size	Percentage by mass passing sieve
10 mm	100
5 mm	89-100
2.36 mm	60-100
1.18 mm	30-100
600 μm	15-100
300 μm	5-70
150 μm	0-150*
* For crushed rock sands the permissible limit is increased to 20%	

Table 7. Leaching limits as set out in Council Decision 2003/33/EC

Element or substance	Inert wastes			Non-hazardous wastes			Hazardous waste acceptable at non-hazardous waste landfills			Hazardous waste acceptable at hazardous waste landfills		
	L/S = 2 L/kg mg/kg	L/S = 10 L/kg mg/kg	C_0 percolation test mg/L	L/S = 2 L/kg mg/kg	L/S = 10 L/kg mg/kg	C_0 percolation test mg/L	L/S = 2 L/kg mg/kg	L/S = 10 L/kg mg/kg	C_0 percolation test mg/L	L/S = 2 L/kg mg/kg	L/S = 10 L/kg mg/kg	C_0 percolation test mg/L
As	0.1	0.5	0.06	0.4	2	0.3	0.4	2	0.3	6	25	3
Ba	7	20	4	30	100	20	30	100	20	100	300	60
Cd	0.03	0.04	0.02	0.6	1	0.3	0.6	1	0.3	3	5	1.7
Cr (total)	–	–	–	4	10	2.5	4	10	2.5	25	70	15
Cu	0.9	2	0.6	25	50	30	25	50	30	50	100	60
Hg	0.003	0.01	0.002	0.05	0.2	0.03	0.05	0.2	0.03	0.5	2	0.3
Mo	0.3	0.5	0.2	5	10	3.5	5	10	3.5	20	30	10
Ni	0.2	0.4	0.12	5	10	3	5	10	3	20	40	12
Pb	0.2	0.5	0.15	5	10	3	5	10	3	25	50	15
Sb	0.02	0.06	0.1	0.2	0.7	0.15	0.2	0.7	0.15	2	5	1
Se	0.06	0.1	0.04	0.3	0.5	0.2	0.3	0.5	0.2	4	7	3
Sn	–	–	–	–	–	–	–	50	–	–	–	–
Zn	2	4	1.2	25	50	15	25	50	15	90	200	60
Cl^-	550	880	450	10000	15,000	8500	10,000	15,000	8500	17,000	25,000	15,000
F^-	4	10	2.5	60	150	40	60	150	40	200	500	120
SO_4^{2-}	560	1000	1500	10,000	20,000	7000	10,000	20,000	7000	25,000	50,000	17,000
Phenol index	0.5	1	0.3	–	–	–	–	–	–	–	–	

5. Stakeholder Product Acceptance and Product Requirements

Stakeholder were identified and interviewed individually. Maldives National Association of Construction Industry (MNACI), contractors, masonry block producers and consultants were interviewed. There were challenges in arranging interviews as some were not available for the interview. Twelve participants were interviewed. Three main questions were asked after a brief explanation of the project, potential applications of r-IBA and processed CDW, and the characteristics and performance of IBA and CDW in various applications. Figure 2 shows the results of the interview. The general response was good with 75% viewing the reuse of IBA and CDW as a good initiative and 65% were willing to buy and use the product. However, almost all the participants imposed a condition on the willingness to buy or use the product. The willingness of potential stakeholders was subjected to the compliance with standard requirements. Some of the participants (25%) view that if the performance of the product made using IBA or CDW satisfy the standards and is similar to the performance of product made with natural aggregates the price of IBA or CDW could be similar to that of natural aggregates. However, 35% of the participants believe the price of IBA or CDW should be 40 – 60% of the price of natural aggregates. A quarter of the participants did not respond to the price question.

It was observed that most of the contractors believe the use of IBA or CDW depend on the approval of consultants and did not suggest any product requirements, other than strength. However, consultants had given additional requirements such as absorption percentage and grading. In general, all participants believed that IBA and CDW aggregates should conform to international standards.

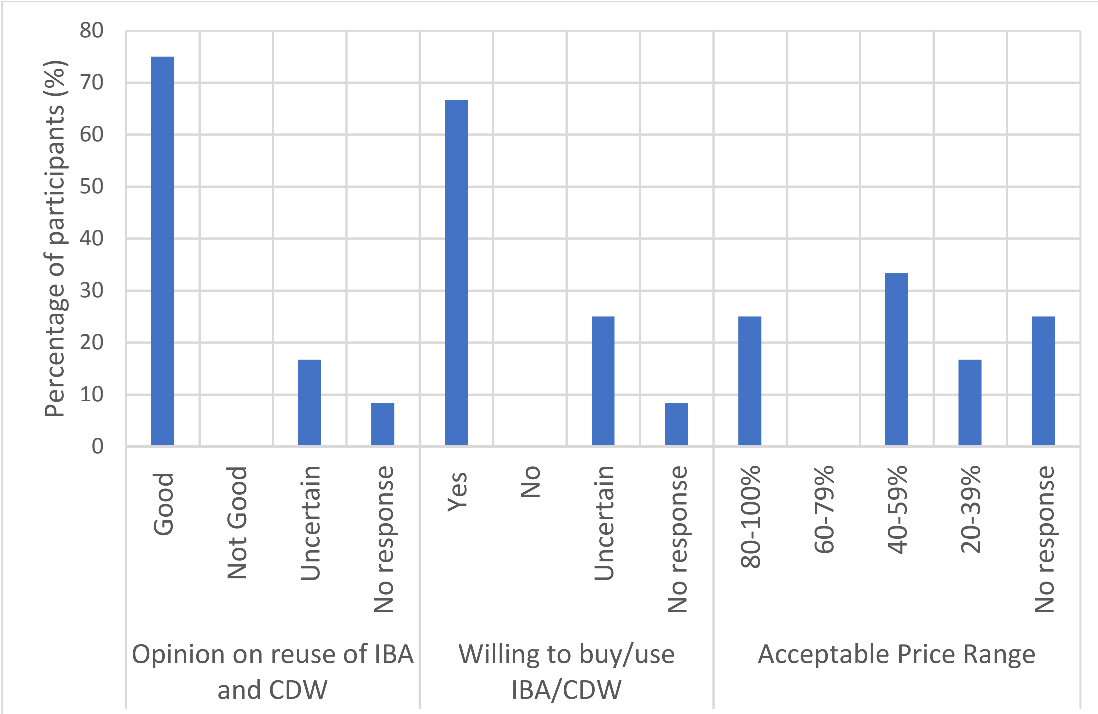

Figure 2. Results of stakeholder consultations on the reuse of IBA and CDW

6. Cost of similar construction materials and current demand

IBA and CDW are substitute products for coarse and fine aggregates used in construction industry. Hence, the demand for IBA and CDW products are expected to be similar to the demand for aggregates. Aggregates is one of the major materials used in construction. The current demand for aggregates should be reflected by the demand in the construction industry. Hence, the trends in the construction industry was first analyzed. The gauges used to determine the current demand is the construction related imports, loans to construction industry, and the building permits issued.

The construction industry is performing progressively as indicated by the gauges. In the first quarter of year 2018, loans for construction of residential housing, guest houses and new resorts observed an annual increase of 19%. During the first half of year 2018 the annual growth in credit to construction industry was registered as 23% and the growth maintained in the third quarter.

Construction related imports is another indicator of the demand in construction industry. The construction related imports increased 51% during the first half of the year 2018 and during the third quarter the growth was 39%. Statistics provided by Maldives Customs Service shows that about 792,800 tons of course aggregates and 495,300 tons of fine aggregates (sand) were imported to Maldives in year 2018 (Table 9). The value of imports of aggregate amounts to USD 48.9 million.

The demand for masonry blocks was captured through interviews. Maldives National Association of Construction Industry (MNACI), one of the largest contractors in Maldives and one of the current major suppliers of concrete masonry blocks to the Greater Male' Region were interviewed. Attempts to access archived information of Maldives Road Development Corporation was not successful. Maldives Road Development Corporation, before its recent liquidation, used to be one of the largest concrete masonry and pavement block production facility in the country. Currently, there are several block producers. Majority of block production facilities operate on a small scale and production is limited to approximately 1000 to 3500 blocks per day. Some of the large contractors operate their own production facilities and produce quantities sufficient for their own projects. Small scale block producers use local sand while in large-scale production, imported manufactured sand is used but local sand is also used to a limited extent.

The composition of the masonry block varies. Some production facilities had adopted a volumetric ratio of 1 units of cement to 5 or 6 units of sand while some production facilities can increase the sand content. Hollow rectangular blocks and solid rectangular blocks are manufactured in Maldives. The width of the blocks currently produced in the market is four inches.

The market rate of unit cost of local sand is approximately USD/kg 0.015. The typical market rate of four inch hollow blocks produced using local sand is USD 0.39 per block, though USD 0.34 per block is available from some of the large-scale producers. The unit price of four inch solid blocks produced using local sand is US 0.52. However, unit price of four-inch masonry hollow blocks produced using imported manufactured sand is USD

0.97. The average production rate of one of the major suppliers interviewed is 15,000 blocks per day. Considering the known masonry block producers in Male' and Hulhumale' and their observed production, it is estimated that approximately 83,000 blocks are produced per day in Male' and Hulhumale'. Estimating 3.5 kg of sand is required per block, production at this rate requires approximately 291 tpd of sand in Male' and Hulhumale'. Adopting 20% as the optimum aggregate replacement level[23], it is estimated 58 tpd of r-IBA are required. The estimated IBA generation of 100 – 125 tpd is more than the quantity required as of year 2019. The demand for r-IBA could be increased through means of government controls on the use of local sand quarried from lagoons.

The current CDW generation is 530 tpd. The proportion that could be recycled and reused is 482 tpd[24]. However, the CDW processing facility proposed to be implemented has a capacity of 200 tpd. The composition of the CDW (Table 8) shows 42.6% of CDW arriving at Male' waste transfer station is concrete and 41% is sand and soil, and 8.1% is rock and gravel resulting from excavation[23]. It is assumed that sand and soil from excavation works will be reused for backfill and landscape works and thus is excluded from the scope of the TA. Therefore, the recycled concrete yield of the processing facility operating at maximum capacity can be estimated as 85 tpd (42.6% of CDW). However, to be conservative for demand estimation purposes, the yield of recycled aggregates is assumed to be same as 200 tpd, the maximum capacity of the processing plant.

There is no data in the feasibility study[23] that suggests concrete and masonry walls are identified separately. On the contrary it seems structural concrete and masonry walls are identified as a single group of concrete. The properties of aggregates derived from structural concrete and concrete masonry walls differ significantly and would influence the potential application for reuse of CDW and the corresponding demand. Additionally, many old buildings that are being demolished had used sand quarried from lagoons or

[23] Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

[24] Water Solutions and Kocks Ingenieure. (2018). *Feasibility Study for an Integrated Solid Waste Management System for Zone III and Preparation of Engineering Design of the Regional Waste Management Facility at Thilafushi.*

beaches and coral fragments as aggregates. Consequently, the concrete is rich in chloride and had caused severe corrosion and cracking in old buildings. One of the main reasons for demolition is structural damage due to corrosion. Reuse of aggregates made from old buildings constructed using coral fragments would lead to corrosion. Given the uncertainty, it is recommended the concrete processed at the CDW processing plant to be crushed and used as sand for concrete masonry block making. Therefore, it can be assumed that 200 tpd of sand would be generated as recycled concrete.

Approximately 291 tpd of sand is required for block production in Male’ and Hulhumale’. The current demand for sand (fine aggregates) in block production is less than the generation of 200 tpd of recycled aggregates and 100 – 125 tpd IBA, out of which 58 tpd can be used for replacement of sand.

Table 8. Estimated composition by weight of CDW[25]

Estimated Composition by Weight for All Loads

Paper	**0.5%**	
Unwaxed OCC		0.5%
RC Paper		0.0%
Plastic	**0.5%**	
Non-bag Film		0.5%
Polystyrene Packaging		0.0%
Rigid Plastic		0.0%
RC Plastic		0.0%
Metal	**0.2%**	
Major Appliances		0.0%
HVAC Ducting		0.0%
Other Ferrous & Non-Ferrous		0.0%
RC Metal		0.2%
Organic	**0.0%**	
Prunings, Trimmings, Branches, Stumps		0.0%
RC Organic		0.0%
Carpet	**0.0%**	
Carpet		0.0%
Carpet Padding		0.0%
RC Carpet		0.0%
Aggregates & Dirt	**91.8%**	
Dirt, Sand, Soil		41.0%
Concrete		42.6%
Asphalt Paving		0.0%
Brick, Ceramic, Porcelain		0.0%
Rock, Gravel		8.1%
RC Aggregates & Dirt		0.0%

Roofing	**0.0%**	
Roofing		0.0%
RC Roofing		0.0%
Insulation	**0.0%**	
Insulation		0.0%
RC Insulation		0.0%
Wood	**7.1%**	
Clean Recyclable Lumber, Pallets, Crates		7.1%
Other Untreated & Recyclable Wood		0.0%
Painted, Stained, Treated Wood		0.0%
RC Wood		0.0%
Gypsum	**0.0%**	
Clean Gypsum Board		0.0%
Painted Gypsum Board		0.0%
RC Gypsum		0.0%
Misc. C&D	**0.0%**	
Glass	**0.0%**	
Electronics	**0.0%**	
HHW	**0.0%**	
Special	**0.0%**	
Mixed Residue	**0.0%**	
TOTAL	**100.0%**	

[25] Water Solutions and Kocks Ingenieure. (2018). *Feasibility Study for an Integrated Solid Waste Management System for Zone III and Preparation of Engineering Design of the Regional Waste Management Facility at Thilafushi.*

7. Forecasted demand

The long-term demand is captured using the same three gauges; the construction related imports, loans to construction industry, and the building permits issued. Historic data was obtained and analyzed to see long-term trends. Future projections were done based on historic data and the current situation of the Greater Male' region.

Statistics published by Maldives Monetary Authority shows rapid growth in construction-related imports over last five years[25] (Figure 3). However, a sudden decline in imports was observed in year 2009. This is because of the Global Financial Crisis in year 2009. Despite global recovery from the financial crisis, significant growth in years 2011 to 2012 was not observed because of the restrictions imposed by India on imports of aggregates. Prior to year 2009, construction industry had been experiencing rapid growth for five to six years. The growth in the construction industry since year 2013 is due to numerous public sector investment programme (PSIP) infrastructure projects, private sector investment in real-estate and expansion in tourism sector. As observed from Figure 3, consumption of construction materials is increasingly observed in private and tourism sector. This suggests the growth in resort development and residential property construction.

Loans to construction industry over recent years exhibit industry growth and support the trend observed from construction-related imports. Credit to tourism sector and construction industry has been increasing since second quarter of year 2015 (Figure 4). Growth in tourism sector is mainly due to lending for construction of guesthouses and new resort development. The growth in lending to the construction industry is due to lending for residential and housing purposes[26].

[26] Maldives Monetary Authority. (2018). *Annual Report 2017*

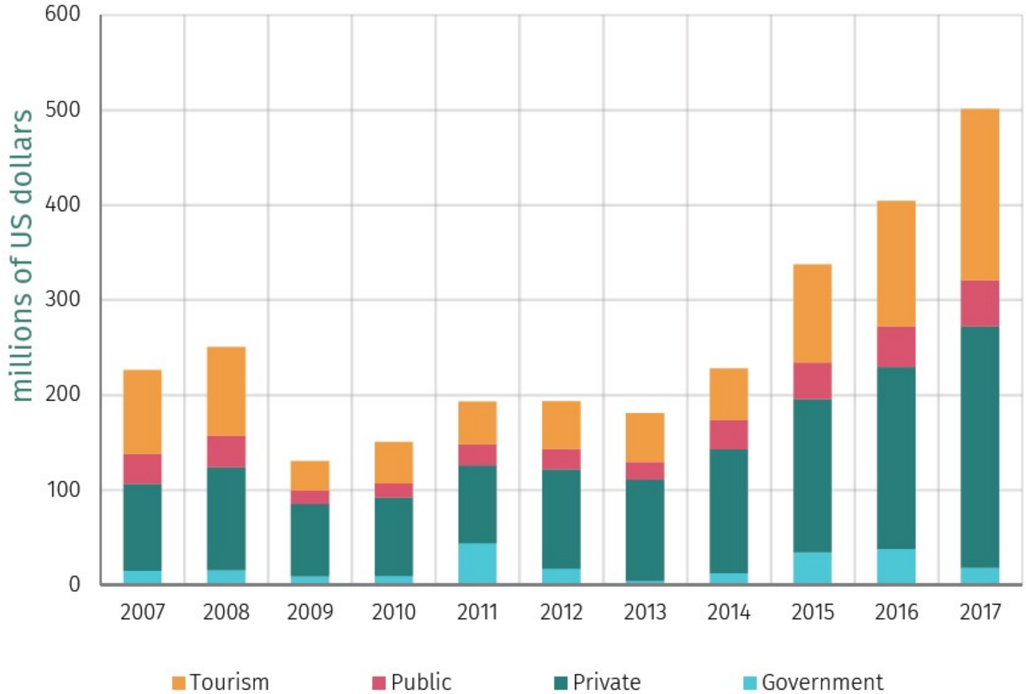

Figure 3. Construction related imports by sector[27]

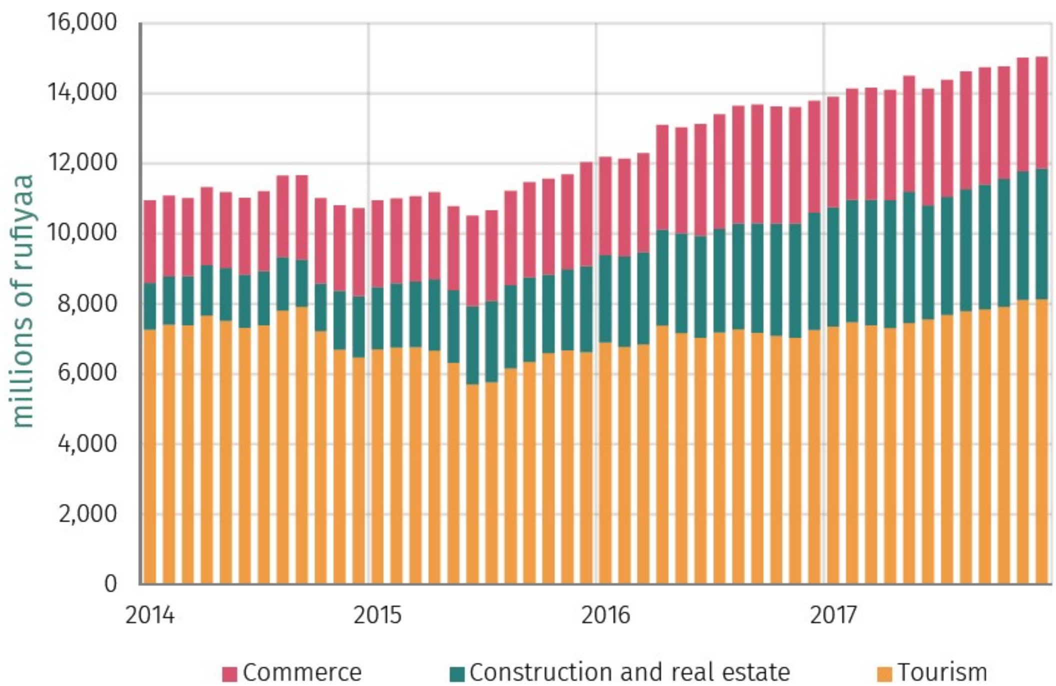

Figure 4. Loans and Advances to the Private Sector by Major Sectors[27]

[27] Maldives Monetary Authority. (2018). *Annual Report 2017*

Building permits is a key indicator of activity in construction industry. There are two types of permits; a permit given to commence construction and a permit given to use the building following completion of construction. Permits are well documented in Male' and Hulhumale'. Building permits available for the last fifteen years is collected and historic trends analyzed (Figure 5). Construction industry prior to year 2009 was a very robust industry with construction permits more than 500 permits annually. The industry was experiencing double digit growth rates[28]. However, the industry came to a halt in year 2009 due to the Global Financial Crisis and it is estimated to have contracted sharply by 16% in 2009 due to delays in major resort development projects owing to declines in capital inflows. Growth for the five years following year 2009 may have been affected by political instability and restrictions in availability of aggregates from India[29]. Since year 2013, with the increase in supply of aggregates, construction of residential buildings has been rapidly increasing and construction activity is similar to the trend observed before the financial crisis.

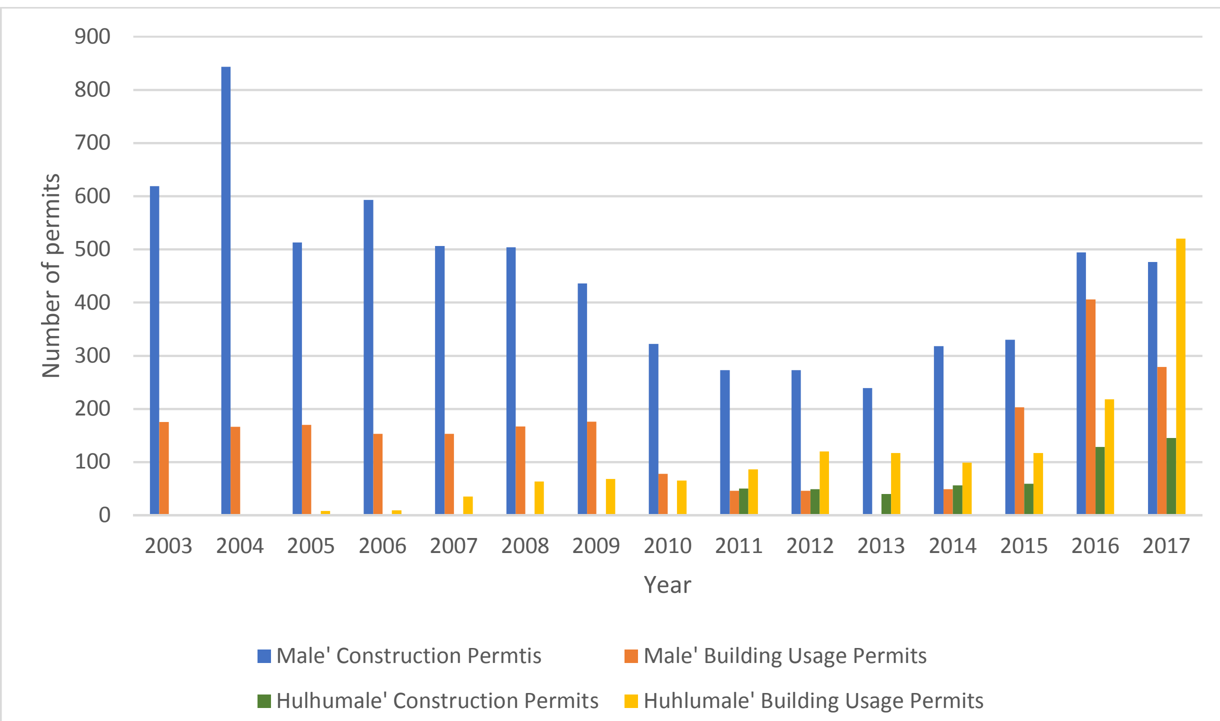

Figure 5. Building permits[30]

[28] Maldives Monetary Authority. (2010). *Annual Report 2009.*
[29] Maldives Monetary Authority. (2014). *Annual Report 2013.*
[30] National Bureau of Statistics, 2004 - 2017

Table 9. Imports of course aggregates and fine aggregates (sand)[31]

Year	Aggregates		Sand	
	Quantity (t)	CIF (MVR)	Quantity (t)	CIF (MVR)
2004	159,426	59,094,523	186,889	57,867,960
2005	191,518	76,128,976	245,979	86,542,799
2006	184,765	82,932,844	258,055	88,612,134
2007	355,762	186,032,748	432,665	200,161,633
2008	327,331	162,881,687	368,997	166,039,942
2009	184,180	86,776,242	165,230	63,140,895
2010	204,082	85,637,549	120,016	53,566,753
2011	267,540	136,810,147	153,877	88,147,309
2012	242,781	138,694,729	84,535	59,297,401
2013	180,492	147,359,782	133,699	105,190,451
2014	270,519	201,915,402	185,217	151,766,876
2015	536,523	344,320,685	226,981	155,857,347
2016	555,891	315,681,933	474,183	168,811,604
2017	803,326	425,625,230	330,156	177,082,708
2018	792,798	413,483,330	495,321	340,574,712

Historic data suggests that the construction industry has been a robust industry. The industry has potential growth due to the undeveloped reclaimed Gulhifalhu island and the recently reclaimed Hulhumale' phase 2. The relative annual growth rates of the last decade, (Figure 6) shows a positive growth. The exception is the year following Global Financial Crisis, where industry experienced a decline. The rate of growth is estimated by finding the average of the percentage growth of the three key indicators in years 2013 – 2017 (Table 10). Over the recent five years, the construction activity in Greater Male' Region has been restored close to the situation before the financial crisis. This is observed from the number of building permits in Figure 5. The average growth in construction related imports, credit to construction industry and construction permits is 22%, 26% and 17%, relatively. The average growth of these three key indicators is 22%.

[31] Maldives Customs Service (2018)

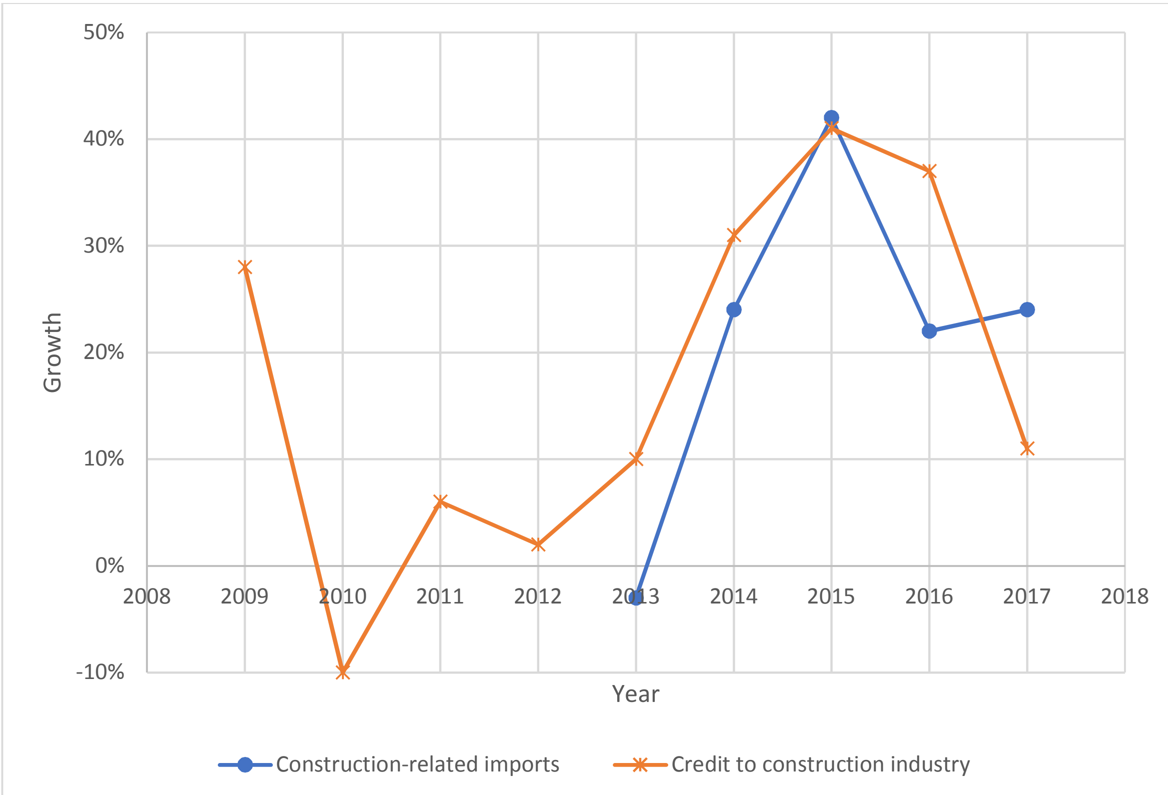

Figure 6. Growth of construction industry relative to preceding year

Table 10. Growth of key indicators of construction industry

Year	Construction-related imports	Credit to construction industry	Construction Permits	Building usage Permits
2017	24%	11%	0%	28%
2016	22%	37%	60%	95%
2015	42%	41%	4%	116%
2014	24%	31%	34%	26%
2013	-3%	10%	-13%	-30%
2012		2%	0%	26%
2011		6%	0%	-8%
2010		-10%	-26%	-41%
2009		28%	-13%	6%

Future total demand in aggregates were estimated based on historic import quantities. The data was obtained from Maldives Customs Services. Quantities of aggregates and sand (fine aggregates) imported to Maldives over last 15 years is shown in Figure 7. It is believed the import quantity of sand obtained is only for river or natural sand and there might be quantities imported in various other names. The trend observed in aggregate imports mirrors the trend observed in the key indicators of the construction industry.

Figure 7.Imports of course aggregates and fine aggregates (sand) over 15 years [32]

Future demand projections are estimated based on historic values using exponential smoothing. Data since year 2011 is taken because Global Financial Crisis is an considered as an extreme and rare event and considering the two years following year 2009 would have affected the accuracy of the forecast. Figure 8 and Table 11 shows the demand forecast of aggregates in the industry for the next 15 years. Figure 9 and Table 12 shows the demand forecast of sand in the industry for the next 15 years. These are the total demand of the industry for aggregates and sand.

[32] Maldives Customs Service (2018

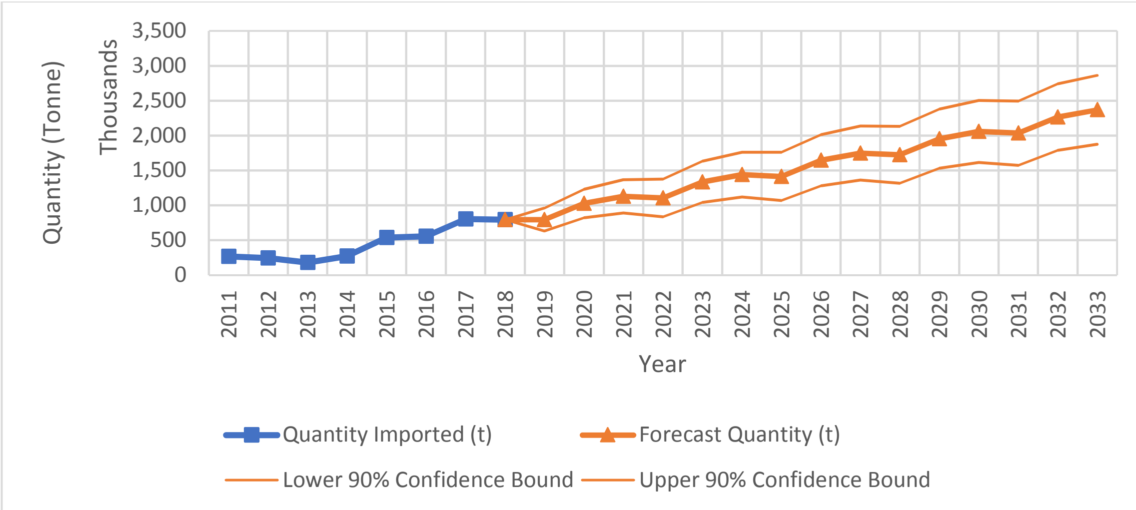

Figure 8. Forecast of course aggregates for 15 years (2018 - 2033)

Table 11. Forecast of course aggregates for 15 years (2018 - 2033)

Year	Quantity Imported (t)	Forecast Quantity (t)	Lower 90% Confidence Bound (t)	Upper 90% Confidence Bound (t)
2011	267,540			
2012	242,781			
2013	180,492			
2014	270,519			
2015	536,523			
2016	555,891			
2017	803,326			
2018	792,798	792,798	792,798	792,798
2019		794,590	630,542	958,638
2020		1,025,770	820,513	1,231,027
2021		1,128,784	889,223	1,368,346
2022		1,104,500	834,815	1,374,185
2023		1,335,679	1,038,913	1,632,446
2024		1,438,694	1,117,056	1,760,333
2025		1,414,410	1,069,571	1,759,249
2026		1,645,589	1,279,015	2,012,163
2027		1,748,604	1,361,461	2,135,747
2028		1,724,320	1,317,546	2,131,094
2029		1,955,499	1,529,999	2,380,999
2030		2,058,514	1,615,032	2,501,996
2031		2,034,230	1,573,378	2,495,082
2032		2,265,409	1,787,819	2,743,000
2033		2,368,424	1,874,620	2,862,227

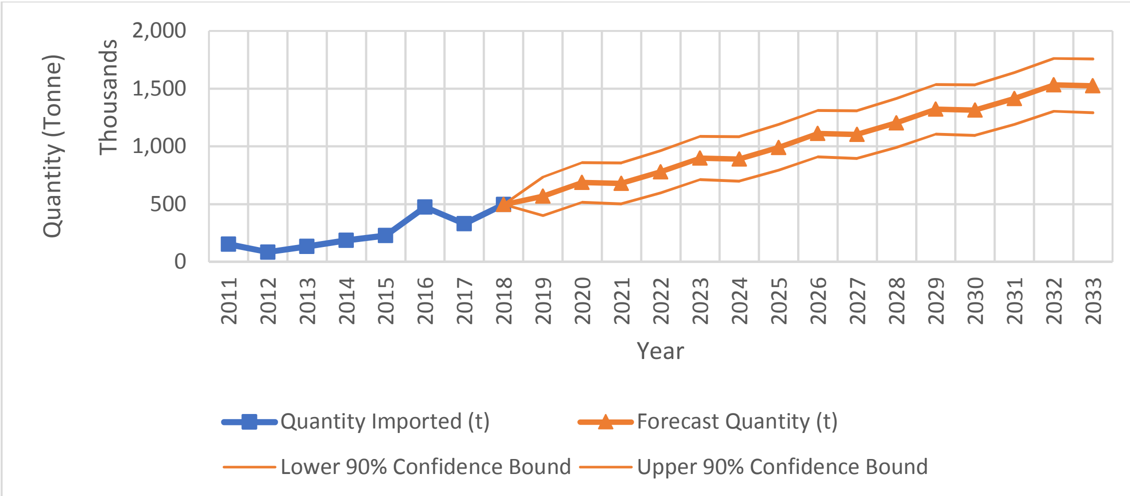

Figure 9. Forecast of fine aggregates (sand) for 15 years (2018 - 2033)

Table 12. Forecast of fine aggregates (sand) for 15 years (2018 - 2033)

Year	Quantity Imported (t)	Forecast Quantity (t)	Lower 90% Confidence Bound (t)	Upper 90% Confidence Bound (t)
2011	153,877			
2012	84,535			
2013	133,699			
2014	185,217			
2015	226,981			
2016	474,183			
2017	330,156			
2018	495,321	495,321	495,321	495,321
2019		568,631	401,394	735,869
2020		688,224	515,758	860,690
2021		680,146	502,565	857,726
2022		779,772	597,143	962,401
2023		899,364	711,822	1,086,906
2024		891,286	698,919	1,083,653
2025		990,912	793,766	1,188,059
2026		1,110,505	908,692	1,312,317
2027		1,102,427	896,018	1,308,835
2028		1,202,053	991,080	1,413,026
2029		1,321,645	1,106,204	1,537,086
2030		1,313,567	1,093,715	1,533,419
2031		1,413,193	1,188,952	1,637,434
2032		1,532,786	1,304,240	1,761,332
2033		1,524,708	1,291,904	1,757,511

There is no historic data available to use exponential smoothing to forecast the sand required for concrete masonry block making. The current demand is approximately 291 tpd of sand for block production in Male' and Hulhumale'. The demand of sand required for concrete masonry block making in the next 15 years is forecasted by assuming a linear growth equal to the estimated industry growth rate of 22%. However, computing growth at a rate of 22% for 15 years result in an exponential growth and is not realistic. Hence, linear growth at 22% is only computed for five years and used as historical values to use exponential smoothing to forecast for the next 10 years. The forecasted demand is shown in Figure 10 and the quantities are given in Table 13. The projected quantity of IBA and recyclable CDW is estimated in the feasibility study (Table 14). The projected IBA and recyclable CDW quantities are compared with the forecasted demand of sand required in block production (Figure 11). The quantity of CDW aggregates is initially more than the forecasted demand of sand used in block production. However, since year 2021, the demand of sand, including the lower bound, is more than the total IBA and CDW recyclables generated.

Figure 10. Demand forecast of fine aggregates (sand) required in concrete masonry block production for 15 years (2018 – 2033)

Table 13. Demand forecast of fine aggregates (sand) required in concrete masonry block production for 15 years (2018 – 2033)

Year	Forecast Quantity (t)	Lower 90% Confidence Bound (t)	Upper 90% Confidence Bound (t)
2018	90,210		
2019	110,056		
2020	134,269		
2021	163,808		
2022	199,845	199,845	199,845
2023	223,809	214,076	233,542
2024	251,494	240,607	262,380
2025	279,178	267,246	291,110
2026	306,862	293,965	319,760
2027	334,547	320,748	348,346
2028	362,231	347,583	376,880
2029	389,916	374,462	405,370
2030	417,600	401,377	433,823
2031	445,285	428,325	462,244
2032	472,969	455,301	490,637
2033	500,653	482,301	519,006

Table 14. Projection of IBA and CDW aggregates generation (Feasibility Study, 2017)

Year	Recyclables of CDW	IBA generated
2018	151572	
2019	153664	
2020	155787	
2021	157944	
2022	160134	
2023	162358	43125
2024	164617	43125
2025	166911	43125
2026	169242	43125
2027	171608	43125
2028	174012	43125
2029	176454	43125
2030	178934	43125
2031	181453	43125
2032	184012	43125
2033	186611	43125

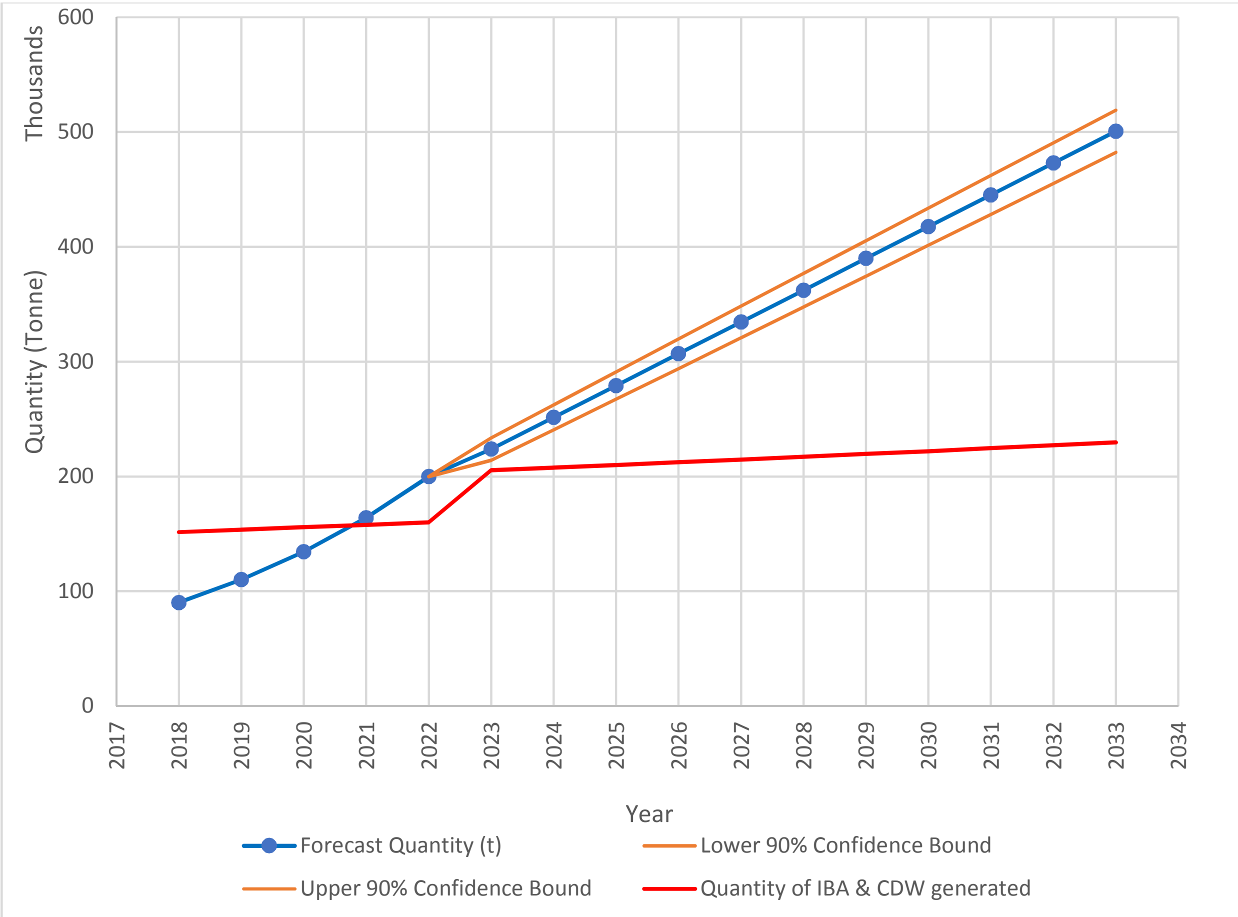

Figure 11. Comparison of forecasted sand required for concrete block production against IBA and CDW generated

A sensitivity analysis was done to evaluate consumption of IBA and CDW in various market share scenarios. The Figure 11 represents IBA and CDW consumptions when 100% market penetration is adopted. Three alternative scenarios were considered; 90%, 80% and 60% of the market share (Figure 12 and Table 15), instead of the 100% market share represented in Figure 11. When 100% market penetration is possible, all the IBA and CDW generated can be consumed by the block production industry. However, when market share reduces to 90% of the forecasted demand, not all IBA and CDW that is generated is consumed in year 2023. Similarly, when market share reduces to 80% of the forecasted demand, there are some IBA and CDW left over in years 2023 and 2024. When the market share reduces to 60% of the forecasted demand, there are some IBA and CDW left over in years 2023 to 2028. The left over IBA and CDW could be used for other purposes like screeds as suggested by the participants interviewed. It is recommended to try to achieve 100% market share. This can be achieved easily by drastically reducing the price of IBA and CDW. IBA and CDW are substitute products to natural aggregates and price is the driving factor that drives demand in substitute products.

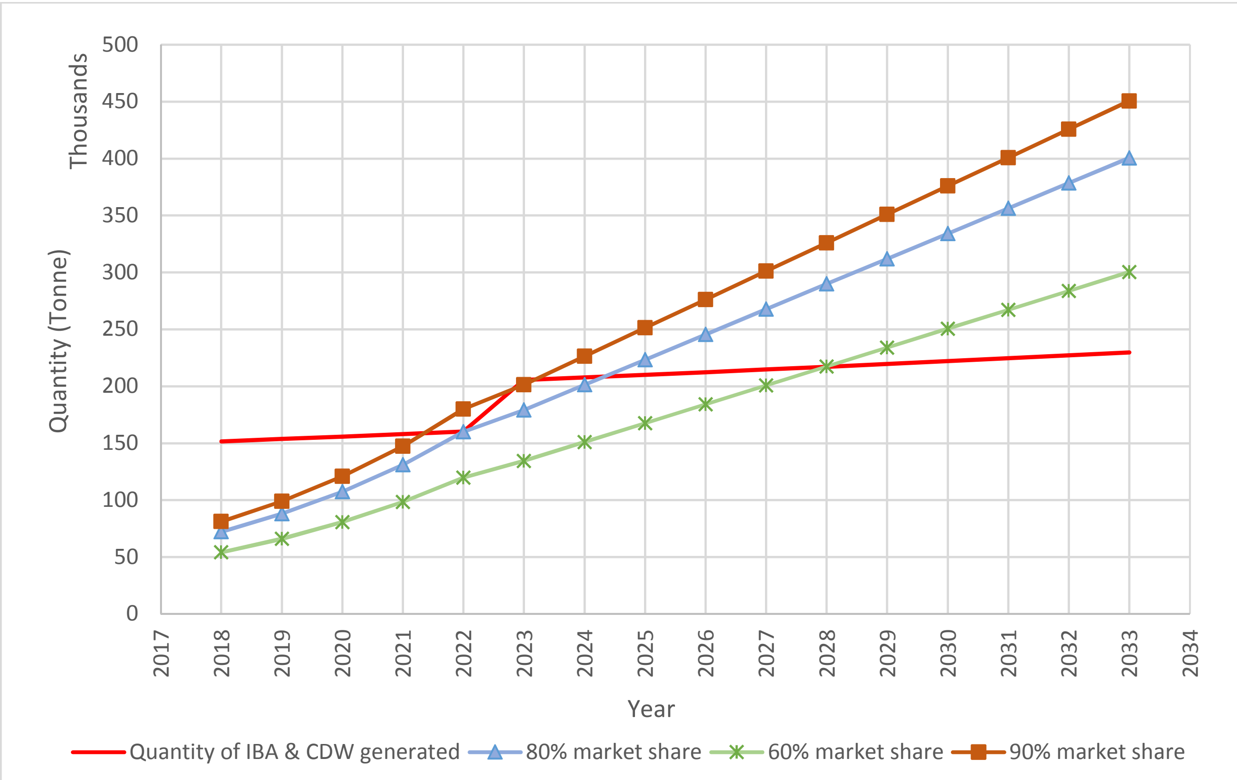

Figure 12. Sensitivity analysis of demand for IBA and CDW in concrete masonry block production

Table 15. Sensitivity analysis of demand for IBA and CDW in concrete masonry block production

Year	90% market share				80% market share				60% market share			
	20% IBA (t)	Unused IBA (t)	80% CDW (t)	Unused CDW (t)	20% IBA (t)	Unused IBA (t)	80% CDW (t)	Unused CDW (t)	20% IBA (t)	Unused IBA (t)	80% CDW (t)	Unused CDW (t)
2018			81,189	70,383			72,168	79,404			54,126	97,446
2019			99,051	54,613			88,045	65,619			66,034	87,630
2020			120,842	34,945			107,415	48,372			80,561	75,226
2021			147,427	10,517			131,046	26,898			98,285	59,659
2022			179,861	0			159,876	258			119,907	40,227
2023	40,286	2,839	161,143	1,215	35,809	7,316	143,238	19,120	26,857	16,268	107,428	54,930
2024	45,269	0	181,075	0	40,239	2,886	160,956	3,661	30,179	12,946	120,717	43,900
2025	50,252	0	201,008	0	44,668	0	178,674	0	33,501	9,624	134,005	32,906
2026	55,235	0	220,941	0	49,098	0	196,392	0	36,823	6,302	147,294	21,948
2027	60,218	0	240,874	0	53,527	0	214,110	0	40,146	2,979	160,582	11,026
2028	65,202	0	260,807	0	57,957	0	231,828	0	43,468	0	173,871	141
2029	70,185	0	280,739	0	62,387	0	249,546	0	46,790	0	187,160	0
2030	75,168	0	300,672	0	66,816	0	267,264	0	50,112	0	200,448	0
2031	80,151	0	320,605	0	71,246	0	284,982	0	53,434	0	213,737	0
2032	85,134	0	340,538	0	75,675	0	302,700	0	56,756	0	227,025	0
2033	90,118	0	360,470	0	80,105	0	320,418	0	60,078	0	240,314	0

8. Sustainable Business Model

The reuse of IBA and CDW as an exported alternative raw material in cement manufacturing, in structural concrete, as a fill material for road bases and sub-base layers, and fill material for land reclamation can be technically feasible as suggested by literature review. However, the financial feasibility or technical uncertainties in the Maldives context limits the reuse of IBA and CDW in many applications that might be viable in other countries.

Considering the logistics involved, the quantity of IBA available for exporting to a cement manufacturer is too small to achieve economies of scale. Similarly, uncertainties in the characteristics of CDW and low performance of IBA replaced concrete limits the reuse of IBA and CDW in structural concrete. The reuse of IBA in road construction is practiced widely in Europe and IBA is used for land reclamation in Japan port areas. However, due to the intermittent frequency and the large volumes of materials required for road and reclamation projects, the reuse of IBA or CDW is not viable for such projects in Maldives.

Concrete masonry block making is an application that has potential for the reuse of IBA and CDW aggregates in Maldives. Based on literature review, the replacement of sand with IBA is technically feasible. The performance of the blocks with r-IBA meets the required standards. Moreover, the demand forecast of sand required in 2023, the planned year to commence incineration of waste, is greater than the amount of IBA generated. Hence, all the IBA produced can be utilized. Similarly, it is recommended to crush CDW to sand size particles and reuse it for masonry block making. The forecasted demand of sand required for block production and the CDW aggregates generated become equal in year 2020, and then the demand is higher than supplied by CDW aggregates. Hence, all the CDW produced can be utilized in the block making industry, assuming 10% market penetration.

There are two business options. The first option is the CDW processing plant operator adopting forward integration and become either a supplier of IBA and CDW aggregates as raw materials to the market or starting a block production business. The consultant does not recommend the first option because the amount of IBA and CDW aggregates generated is much less than the market demand. To create a demand for the product, the operator should ensure reliability of the availability of the product in quantities demanded by the market. This concern was raised by one of the large contractors interviewed. The contractor noted he would be willing to purchase IBA and CDW at a lower cost for his block production if a continuous stream of raw materials is ensured. The contractor highlighted that IBA and CDW depends on the availability of waste, which can be variable, and hence questioned the reliability of the availability. Furthermore, IBA and CDW would probably be used to replace part of the natural sand used. Hence, contractors or block producers would like to get all the required sand from one place. In such cases, the operator might be required to get into the business of importing sand.

The second option is to use an intermediately aggregate supplier like State Trading Organization (STO) instead of directly selling it to the market. This option is more recommendable because it eliminates the risks and costs associated with trading with the market directly. STO is one of the major aggregates supplier and has established customer bases and distribution networks. Hence, adopting the second option is financially more attractive.

Table 16 shows the price comparison of different types of sand used for block production. The price of IBA and CDW aggregates are the prices suggested by the consultant in the feasibility study. As observed the unit price of IBA and CDW aggregates are significantly cheaper. Since the materials are substitute goods, a drastic reduction in price would increase the demand for the IBA and CDW aggregates, provided the performance is assured.

Table 16. Price comparison of sand used for concrete masonry block production and IBA and CDW

	Price (MRV/Mg)	**Price (USD/Mg)**
Sand (fine aggregates)	794.18	51.5
Local sand	225	14.59
IBA	77.1	1 – 5
CDW aggregates	33.55	1 – 2.18

9. Recommendations

Concrete masonry block and pavement block production is a potential application for utilization of IBA and CDW in Maldives. Use of IBA and CDW in non-structural applications such as use in floor screed concrete could be a potential market too.

The demand forecast shows the generation of IBA and CDW could be less than the demand required by the block production industry, provided 100% market penetration is possible. It is recommended that Government should promote the use of IBA and CDW through campaigns to assure the technical and safety suitability of the waste products.

The general response of stakeholders consulted is promising and many are willing to accept the product if the price is significantly lower than natural aggregates and the performance of the product meets the standards, often international standards.

There are no existing local standards directly related to IBA or CDW, mainly because these are new products in the Maldivian market. However, new regulations governing the reuse of IBA and CDW should be expected soon as Ministry of Environment is in the process of formulating environmental regulations to IBA and CDW. Hence, it is suggested that treating of IBA and CDW is critical to ensure the characteristics and performance confirms to international best practices and consequently the acceptance of r-IBA and processed CDW as a building material in Maldives.

It is recommended to introduce the products to the market through intermediately aggregates supplier. Additionally, the price should be significantly lower than natural aggregates to drive the demand for IBA and CDW.

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