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Efficient Reuse of Railway Track Waste Materials

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Abstract: Some of the most important materials that need recycling are generated by the construction industry. This waste has a multitude of disposal problems. In the specific case of railways, the treatment of materials taken from track maintenance and renewal operations is even more challenging. Every year, tons of track materials are replaced on rail tracks all over the world. These kilometres of rails, sleepers, and tons of ballast can be reused for other purposes. However, sometimes the environmental cost generated by their secondary use is worse than the problems involved in their disposal. This work describes a revised methodology to improve the recycling process of these waste track materials and considers the carbon footprint generated during the process along with important advantages and benefits for the economy and the environment. The reuse of these worn track materials is important to extend their life cycle and reduce environmental and economic costs in the long term. This research aims to analyse dismantled track material and evaluate possible second uses, taking into account the carbon footprint generated. Special attention has been placed on environmentally friendly uses such as fencing protected areas or green routes, among others.

Keywords: life cycle cost; environmental cost; waste track material; recycling; second use; carbon footprint

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1. Introduction

The disposal of construction waste materials is an important environmental issue. Generally speaking, most types of waste materials are difficult to dispose of. Track material is not an exception as it is not easy to reuse or recycle some of the elements involved. An additional problem is how to quantify the environmental cost of the recycling process.

Track structures involve a superstructure, the visible part of the railway track, and infrastructure, the invisible part (under the superstructure and close to the ground). Track elements such as rails, fastenings, sleepers, ballast, and subbase are common materials with limited lifespans, so they have to be removed and replaced. This used material usually has two ends. One of them is to be recycled or reused for creating new materials or giving them new uses for other purposes. The other way is to just dispose of them in an appropriate landfill (with the corresponding problems of storage and pollution).

The materials can be reused mainly by following two processes: (1) direct reuse, which means that material can be reused as it is, and (2) in an indirect way, where the material needs a major transformation to be used again. To make the recycling process efficient, materials need to satisfy several economic and technical requirements. Another really important prerequisite is related to environmental concerns. It is important to recycle materials, but the efficiency of the process needs to be understood, as recycling can be better or worse in terms of its carbon footprint.

This paper tries to clarify the latter question and provide some additional solutions for reusing and recycling track waste materials, addressing not only the economic aspects but also the associated environmental concerns, as the second life of these materials can be directly used to make environmental improvements.

The paper is structured as follows: in Section 1, the authors introduce the problems of efficiency during the process of recycling used track materials. Section 2 describes the state of the art of the different options and new uses for these materials (direct and indirect uses). Section 3 presents the methodology proposed by the authors to develop an efficient second use for these materials. After the methodology, a case study is proposed (in India). Results and options are described in Section 5, the discussion. Finally, some remarkable conclusions and useful recommendations are proposed.

2. State of the Art Review

Rail track structures (superstructure and subgrade) contain a lot of materials. Their structural integrity must be constantly monitored along with regular maintenance. Track maintenance and track renewal generate a lot of waste products and materials, most of which are problematic to eliminate.

The platform and the rails forming the track structure contain a lot of different types of materials. The estimated life of these materials depends on the resistance of the material and the type of working loads (i.e., normally millions of tons of traffic). Broadly speaking, values can go from a 10-year lifetime for rails, to 40 years for the sleepers and more than 40 for the subbase material. Table 1 shows the estimated life spans of the most important track materials [1]. These values correspond to the most typical maintenance cycles in Germany and represent the average life cycles of each material.

Table 1. Estimations of track material life spans. Conventional values for track renewal [1].

Track Element	Traffic (Millions of Tons)	Years (Estimated Time before Changing the Track Element)
Rails	300–1000	10–15 years
Sleepers	350–700	30–40 years
Fastenings	100–500	10–30 years
Ballast	200–500	20–30 years

Life spans can be affected not only by the material itself or the loads being supported but also by the disposition and geometry of these track elements. For instance, recent studies show how material life spans change with their disposition along the track, e.g., an increase in sleeper spacing (distance between sleeper axes) can decrease their useful life. Table 2 shows these changes in relation to sleeper distance [2]. It shows how the values in Table 1 can vary considering the distance between sleepers if we consider a proportional estimation. The values shown in the table are taken from [2], and to simplify the calculations, the worst case (higher value) was taken.

Table 2. Lifetime estimation considering the distance between sleepers [2].

		Proportionally Estimated			
Track Element	Rounded Values	Distance 0.7 m	Distance 0.8 m	Distance 0.9 m	Distance 1.0 m
Rails	15 years	12 years	10 years	7 years	5 years
Sleepers	40 years	30 years	26 years	20 years	13 years
Fastenings	30 years	25 years	20 years	15 years	10 years
Ballast	30 years	25 years	20 years	15 years	10 years
Platform	>40 years	>30 years	>26 years	20 years	13 years

All these track elements from rails to subbase can be reused. For instance, recycled rails can be used to improve track transition solutions [3]. Other authors [4] describe a new rubber highway that combines a road suitable for automobiles and a railway track.

There are two principal ways of treating these materials: (1) Give them a second opportunity to be reused in a direct way or an indirect way or (2) send them to a landfill and end their life cycle. On some occasions, these scrap materials can cause crime problems such as metal theft [5].

Several examples of the indirect use (e.g., treatments) of iron scrap from rails can be found in [6–10]. The Indian Railways guidelines [6] outline both direct and indirect uses of track waste material. A novel methodology of recycling iron scrap using a machining process is explained in ref. [7]. The dispersed iron scraps were compressed into iron scrap cakes by using an auto hydraulic metal block machine. This novel method is being applied in China, using iron scrap cakes to replace pig iron. The resulting tensile strength of cast test bars was improved with a slight increase in hardness. Researchers in [8] propose another methodology to produce a stainless steel-clad plate by hot rolling. The final material showed good mechanical properties with a strength of up to 273 MPa and good ductility, etc. Research into the effects of different percentages of iron scrap in concrete is presented in ref. [9], testing to find the optimum percentage of adding different amounts of fly ash. During the tests, it was observed that the addition of iron scrap improved the flexural strength of concrete, suggesting it as a cost-effective and structurally efficient material for many Civil Engineering applications. Vardham's Steels in India [10] processes scrap rails into steel bars for housing, steel sheets, steel pipes, steel wardrobes, and other household items.

Some of the methodologies are taken directly as a reference, but the authors would like to propose another way of indirectly using scrap iron waste. The various existing techniques in the case study for the indirect use of sleepers focus on new concrete mix designs. The various crushing sizes used in the concrete mix design and the concrete sleepers play one of the most important roles in the success of the design [11,12]. Depending on particle size, the ballast taken from renewal operations can also be used in the concrete mix design, and they discussed the properties of ballast used as an ingredient in cement manufacturing [13–15].

The cement used in concrete is an important issue if we focus on Green House Gas emissions (GHG emissions) [16,17]. Cement manufacturing produces 7% of the CO_2 in the environment [18,19]. The calcination process alone contributes approximately 50% out of the 7% of CO_2 emitted into the atmosphere, with the remaining 50% of the energy being used in the cement manufacturing process [20,21].

Wastes due to industrial activities are harmful and cause great damage to the environment [22,23].

It can be seen from the state of the art that there are many studies about these processes and the characteristics of the resulting materials, however, none of them addresses the efficiency of the process itself. It is important to reuse materials, but it is also important to think about the methodology being followed during recycling and reuse. The economy and the environment are two important factors to be considered by researchers.

This last premise has led the authors to study and analyse the carbon footprint of both direct and indirect processes in order to assess their efficiency. Therefore, the authors propose a methodology to increase the efficiency of the processes involved in the recycling and reuse of railway track materials.

The following methodology proposes second uses for track waste materials. The total cost of the processes and the resulting carbon footprint estimation are crucial in analysing their efficiency.

Various methods are available to calculate the carbon footprint generated by the process [24–26]; some of them simply use vehicle emissions during displacements [24] depending on fuel consumption (amount of fuel, distance travelled, etc.).

Some useful examples of carbon footprint calculators [27] have been used to calculate the resulting carbon footprint generated by some metal track waste materials, such as rails and fastenings.

The carbon footprint is calculated according to the distance travelled and the machinery being used. In the case of both direct and indirect use, the activities are measured from origin to destination; for example, loading the scrap at the source to unloading the scrap at the destination can generate a high percentage of carbon. The most powerful machines being used in these operations and the cost of fuel, the time spent, etc.

Existing waste treatment policies need reviewing. To this end, the authors would like to propose a review and analysis based on the Indian Railways guidelines [28] and European waste policies [29].

Current European waste policies highlight the importance of recycling the used materials coming from railway tracks, along with other important uses related to the direct and indirect use of these materials. Various recycling methods are explained which are useful for recycling in an appropriate way and further analyse ways of keeping carbon emissions down as much as possible [29].

In order to comply with these new methods of reducing waste products, there are two main forms of reusing waste track materials (schematic, Figure 1).

– Direct use: Waste material has a second opportunity to be reused. Direct use consists of using these materials for other purposes by taking items such as rails or sleepers from the track and reusing them for slope stabilisation [6,28,29].
– Indirect use: Here, the used material needs to be transformed and reused again, e.g., melting down the rails and using the metal for making steel pipes or tubes [7–15].

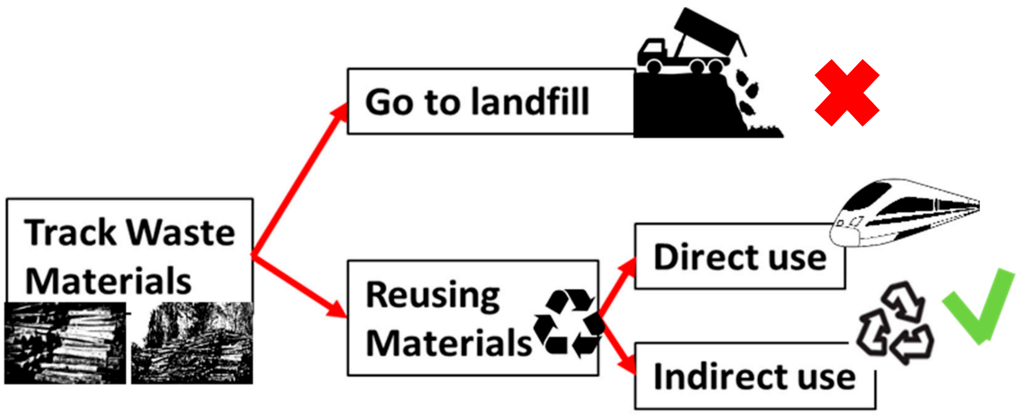

Figure 1. Options for track scrap material.

The following sections explain these two main ways of reusing track materials, pointing out the advantages and drawbacks associated with each method.

2.1. Direct Uses

This section introduces the direct uses of all the materials found in railway superstructures: rails, fastenings, sleepers, and ballast.

There are various ways of classifying reused track materials. One way is to focus on the new uses made of this recycled material and another is to focus on the type of track material and specify all the possible uses.

Different types of rails resist according to the different geometries and materials used in their creation. In Spain, the common types are characterised by their weight, UIC 60 (meaning 60 kg/m) and UIC 54 (54 kg/m). Other countries use heavier rails; the USA uses rails of 90 kg/m. After being used, rails can be reused for many purposes. Some of them are listed below:

- Dead-end railway structure (Figure 2, left). These structures are usually made of scrap second-class rail. The dead end is made to stop the train or prevent the train from leaving the track while shunting at what would otherwise be an open end.
- Rail fencing (Figure 2, right). Fencing made from old rails is very effective as it prevents direct access to the tracks. This fencing is needed, for example, in sections close to urban areas and forest areas. By fencing off specific areas, serious accidents involving humans and animals can be prevented.
- Checkrail (Figure 3, left). Checkrails are used at level crossings to prevent wheel flanges from making direct contact with the ground.
- Guard rails (Figure 3, centre). Guardrails are used to prevent the train from derailing. The guardrail is also made of second-class scrap rail, which is the material most used in railway superstructures. The ends of guardrails should be bent vertically and buried with a block of timber fixed at the end to avoid any entanglement with loose-hanging couplings.
- Support structures along the track. These usually use waste rails as supporting structures. For example, in track structures (masonry supporting tunnels under the tracks) and to help support ballast retaining walls (Figure 3, right).
- Rail pegs (Figure 4, left). Rail pegs are generally used for marking out the ground around tracks when carrying out survey work and along transition curves. These pegs play a vital role during new construction or when making improvements to tracks.
- Slope stabilisation, rail-driving (Figure 4 centre). It is common practice to sharpen second-hand rails and drive them into the natural ground to stabilise the soil and tie soil layers together.
- Fishplates are used as dead weights to stabilise shelves in shops or warehouses (Figure 4, right).
- Rails used on secondary tracks. If rails are not damaged or worn, they can be reused as rails along secondary tracks, parking tracks, and shunting tracks. This use can only be made when the rails are in good condition (Figure 5).

Figure 2. Dead end (**left**). Rail fencing (**right**).

Figure 3. Check rail (**left**). Guard rail (**centre**). Supporting track walls for ballast contention (**right**).

Figure 4. Rail pegs (**left**). Slope stabilisation with rails (**centre**). Fishplates for supports (**right**).

Figure 5. Katni–Damoh rail yard, where a train is being temporarily held(**left**). New holding line for freight trains at the New Katni Junction Yard (**right**).

The normal use of rail fastening is to fix the rail and sleepers in their original position. However, when these plates are worn, alternative uses can be found for them. In India, all of these fastenings are normally used in railway yards. The Indian government invests billions of dollars in the maintenance of railway lines and, in order to save money, railway companies reuse these worn spikes, base plates, and screws on secondary tracks. The government can, therefore, save a considerable amount of money by avoiding investment in new material for less densely used tracks and in yards.

Other small track materials such as parts used in rail joints can be used as counterweights, which help to stabilise and support shop furniture (Figure 4, right), among other direct uses.

There are many different kinds of sleepers depending on the material used. Wooden sleepers, steel sleepers, and concrete sleepers (reinforced, prestressed, and post-tensioned sleepers). This section presents some interesting secondary uses for this kind of track material. Sleepers are separated by, on average, 600 mm, which means there is a great deal of them along the railway line. Some studies analysing sleeper spacing have shown that the spacing can be increased, meaning that railway engineers can build viable tracks with fewer sleepers [2]. Used sleepers can be used for the following purposes depending on the sleeper material and their end use:

– Platform base (Figure 6, upper left). Dismantled pre-stressed sleepers can be used as a base material for making platforms. These areas are located at road level and are only used by freight trains, so any train arriving or departing can be easily accessed for loading and unloading cargo.
– Information panels, areas for storing trollies, and ballast alignment. In this example, the used sleepers prevent the realignment of the base of the ballast in highly sloped land, avoiding any ballast displacement (Figure 6, upper right).

Figure 6. Sleepers are used for making platforms at goods loading areas (**top left**) that are accessible by both road and rail. Ballast alignment along sloped areas of the track to avoid ballast movement (**top right**). Roadsides to separate pedestrian areas (**bottom left**). Pathway sides (**bottom right**).

In Figure 7, left, sleepers are used for making trolley parks; the trolley is the vehicle used for inspecting the track.

- Marking railway boundaries (Figure 7, right). This use is extensive throughout the Indian railway network. India generally uses scrap sleepers for marking property boundaries; this landmarked area is accessible to Indian Railways management for the purpose of delimiting the line to protect property such as rails, fixtures and fastenings, sleepers, ballast, etc.
- Pedestrian boundaries, pathway borders (Figure 6, bottom left). This is to separate pedestrian areas from vehicles.
- Pathways made with sleepers (Figure 8, upper left). Here, the sleepers are directly used for making pathways, so railway workers can access the track for maintenance. They are kept at least 2 m from the track. Pedestrian pathways can be built with used sleepers (Figure 8 upper right).
- Blocks to keep the rail a specific distance from the platform (Figure 9). Sections of blocks taken from wooden sleepers can have various uses across the superstructure. Figure 9, on the left, shows wooden blocks used every 30 m to stop any lateral movement of the track towards the platform.

Figure 9, right, shows the use of wooden blocks beneath sections of welded rail. The main objective is to absorb the impact force created by wheels in this area. Wooden blocks are preferable over other materials such as iron or concrete because the impact loading from wheels can fracture stiffer materials.

Figure 7. Information panel with sleeper steel beam (**left**). Rail land boundary marker (**right**).

Figure 8. Pathways made of concrete sleepers (**above**). Fencing using wooden sleepers (**below**).

Figure 9. Blocks made from wooden sleepers used to maintain the rail's distance from the platform (left), to keep the separation between guard rails at the end of adjacent sides to grip well and erode less (centre), and to support and absorb wheel impact under fishplate joints at welded sections.

– Slope stabilisation (Figure 10). This is another structural use for sleepers. For instance, wooden sleepers can be used adjacent to rivers and lakes to help stabilise slopes containing loose materials.
– Fencing (Figure 8, below). Wooden sleepers can be used for fencing and gardening purposes (Figure 11, above). Rail fencing is useful in gardens to provide borders to separate green from pedestrian areas (Figure 8, bottom left), other uses can be for separating roads from pedestrian areas (Figure 6, bottom left). This type of fencing made from used rails is often used in urban areas, close to the stations and in forested areas, in order to protect human and animal life.
– Other uses. Wooden sleepers can be reused for other purposes away from the tracks. Because of their versatility, these strong wooden elements can be integrated into any environment. The following figure shows some of these alternative uses (pathways, stairs (Figure 11, top left), picnic tables (Figure 11, centre right)). An important application could be to use them as house-building materials (Figure 11, below). The architect Shin Takasuga built a house made of railway sleepers on Miyake island (Japan) [30].

Concrete sleepers can be reused in similar ways to wooden sleepers; however, their use is complicated by their weight—300 kg per concrete sleeper compared with 80 kg for wooden sleepers. They are more difficult to transport and place due to their greater weight.

It is important to appreciate the new applications available for these elements.

– Extra side space (Figure 12, left). This direct use is very common across the Indian railway network. Dismantled ballast is used for aligning the sides of the track to provide an even balance.

Figure 10. Slope stabilisation with second-hand wooden sleepers.

Figure 11. Uses in gardening (**top**). Steps (**centre left**). Picnic tables (**centre right**). Sleeper house in Japan (**bottom**) [30].

After the completion of deep screening using a ballast cleaning machine, the very fine smaller ballast can be used for siding to provide proper supporting alignment. This material can also be used to cover the areas around the slab track and give them a conventional ballasted track appearance.

Another direct secondary use for railway ballast is to fill countryside pathways (Figure 12, right).

Figure 12. Extra side space (**left**). Pathway filling (**right**).

Railway track ballast settles and degrades progressively under heavy train loads Ballast degradation is impacted by several factors including the number of load cycles, the density of the aggregate material, track confining pressure, angularity, and, most importantly, the fracture strength of the individual grains [31]. The degraded ballast is cleared from a location along the track and is then fully or partially replaced by fresh ballast, depending on track settlement and current density. The disposed waste ballast can be cleaned, sieved, and reused on the same track; however, due to breakage along the sharp edges and the development of micro-cracks during the previous loading cycles, recycled ballast is generally subject to excessive settlement and particle breakage. Therefore, the settlement and degradation aspects of recycled ballast must be carefully examined before directly reusing it for its original purpose on the track.

2.2. Indirect Uses

Track waste materials can also be used to make new materials. In this case, the old used materials need to be transformed. These processes are more sophisticated than those with direct use. In most cases, it is more expensive and generates increased environmental costs. Steel scrap material from steel rails and steel fastenings and other smaller track elements can be transformed into other useful materials (Figure 13).

Figure 13. Scrap material of steel from rail track superstructure. Rail and steel sleeper (**left**), lag screws from fastenings (**centre**), and rail joints (**right**).

Re-manufacturing the steel from old rails can provide a lot of raw material for the steel industry, but this process generates high levels of CO_2. The final use of the material needs to be known to evaluate the profitability and efficiency of the process. In the following subsections, the authors will introduce some of the more important indirect uses.

The new material produced from scrap iron is generally roll-bonded clad plate stainless steel. The iron scrap is cold pressed through stainless steel pipes before being hot rolled to generate composite clad plates. The scrap iron is compressed into solid steel and then given an outer surface of stainless steel. The shear strength of this bimetallic product was found to be 270 MPa. These clad plates were shown to have good bending ductility. The peak hardness is reached at the interface of extreme plastic deformation with high temperatures and rolling processes [7] (Figure 14, centre).

Other ways of reusing scrap iron are with machine tools. The iron waste is recycled and held for drying before being treated for surface rust prevention. The process avoids the use of machine-cutting liquids on the surface of the metal scraps in order to create a more environmentally friendly machine-cutting and cooling method. It is important to clean or pre-treat the scrap before compressing it into cakes. Usually, it is sieved before introduction into the cutting machine to remove fluid, dust, and debris. Any rust on the metal surface needs to be removed beforehand. The properties of the metal cake are tested before sending them off for mass production [8].

Experimental studies on the use of metal scrap with fly ash concrete. This process is based on mixing fly ash waste from power plants with waste scrap iron and then checking its strength along with other factors before using it in building structures. The main aim is to reduce the amount of naturally damaged materials by converting them into useful building products. These materials, when added to concrete, provide greater strength than more traditionally used concrete mixtures. This material has been successfully used in various building projects [9]. An example can be seen in Figure 14, right.

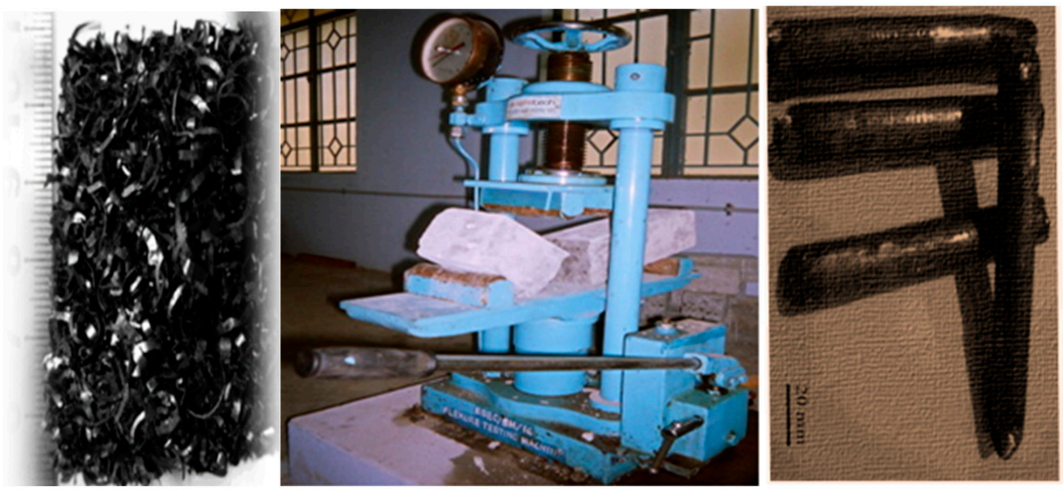

Figure 14. Stainless steel/scrap iron (**left**). Mechanical separation steel-concrete (**centre**). Metal scrap in fly ash concrete transformed (Vardhman Steels Jashi, Madhya Pradesh India) [7] (**right**).

The steel bars used in construction are made from scrap railway steel. Second-class scrap steel materials (rails, steel sleepers, steel fastenings, and so on) are widely used in India, where they are applied to help support concrete structures such as boundary walls, modest retaining walls, buildings, shopping malls, and so on. Angles, steel sheeting, steel pipes, steel racking, water drilling pipes, steel netting, and so on are examples of other applications [10].

Rail fastenings also have indirect applications. There are two main methods of reusing this material. The rail fastening is something of a small item that is not easily handled due to the high number of them distributed along the railways. As they are difficult to directly use in other types of structures, they are normally reused by Indian Railways on secondary tracks or in yard areas, where the fastenings are not subjected to so much wear. Apart from this application, any remaining fastenings are sent for recycling, which has been discussed in other case studies [8,10].

1. Steel bars used in construction are made from scrap steel. These materials are widely used in the Indian construction industry (Figure 15).

2. The recycling and reuse of scrap iron using machining tools. The scrap iron is stored for drying and then reused after protecting it from surface rust.

Figure 15. Steel bars for reinforced concrete (**left**). Boundary walls (**right**) [7].

These two methods can be used for turning the scrap iron into items such as keys, fish plates, spikes, screws, etc. The rubber from the pad can be either sold as scrap or used in concrete mix designs.

Depending on the material they are made of, sleepers can be reused for different indirect purposes, the most important of which are presented below.

- The recycled aggregate from concrete sleepers can be used in making new concrete. The current method is to create a concrete mixture in which the aggregates can be reused in making new concrete structures. The aim is to reduce the environmental pollution caused by concrete waste from existing structures. Here, the polymer concrete is developed by mixing orthophthalic unsaturated polyester resin, artificial micro fillers, and waste aggregates. Variations in the physical properties of concrete are being investigated. These variations come by changing the quantity of aggregate used and testing the different resulting strengths [11].
- Construction recycling and waste demolition to produce polymer concrete. Suitable aggregates from waste material are collected, sorted by removing the surplus debris, and then used in making fresh concrete. The interest here is to use recycled waste and demolition waste with polymeric resin to make polymeric mortar concrete. The mechanical and physical properties of this concrete have to be tested before it can be used in superstructures. The compressive strength and its density need to be classified by varying the mortar mix. Research has tested two types of construction and demolition waste as possible aggregate substitutes (waste cement/concrete debris and waste blocks) along with two types of polymer resins (unsaturated polyester and epoxy) as alternatives to cement. The used weight percentages of the resins were changed (10, 20, 25, and 30%) during the manufacture of polymer concrete [12].
- Plastic sleepers. Recent studies have tried to reduce the dumping of mixed plastic in landfills as a response to the demands of the railway sector. When properly treated, mixed plastics from landfills could be used to manufacture new sleepers and when the life of these sleepers comes to an end the plastic can be reused yet again [32].
- Discarded ballast used in ecological cement preparation. This use for ballast was found in [13] where the use of discarded ballast during the process of cement manufacturing is explained. The ballast is used during different stages of the cement production process. The inclusion of pozzolana during the concrete manufacturing process was found to improve its hydraulic properties. Pozzolanic materials were added to Ordinary Portland Cement (OPC) in the range of 10–20% by mass of cement. An example is phyllosilicate kaolinite (K) and its calcinated derivative metakaolin (MK), used as standard in international cement manufacturing factories because of its high reactivity and utility as a pozzolana. The discarded ballast is classified as construction and demolition waste and reused as a pozzolanic material. The compressive and

flexural strength of discarded ballast as a substitute for cement at levels of 10% and 20% produced types two and four pozzolanic cements and gave satisfactory results [13].

Figure 16 shows the comparison of percentage components of Ordinary Portland Cement and the sample of this new cement material.

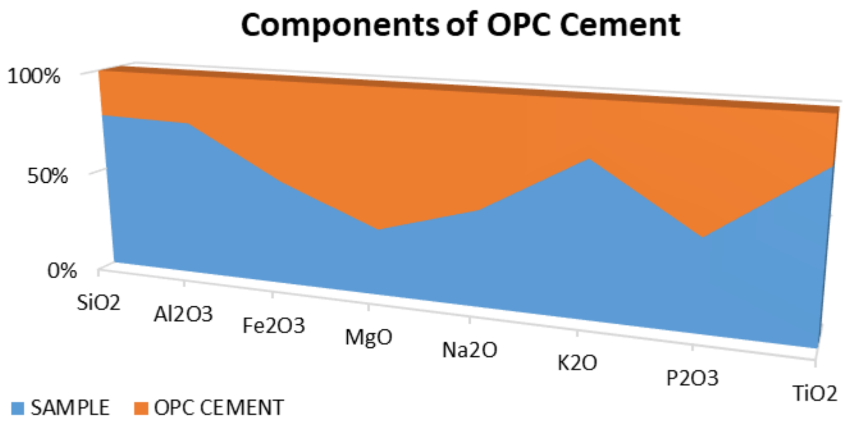

Figure 16. Chemical analysis of OPC Cement [13].

Ballast is one of the key components of railway tracks, allowing rainwater to drain away and providing stability to the track. The ballast deformation and degradation found under static and dynamic loads were based entirely on triaxial testing. The inclusion of geosynthetics was found to coincide with improved ballast properties and shown to improve the performance of ballasted tracks [15].

The use of discarded ballast on other tracks is practically impossible due to the specific properties required from the ballast layer.

Regarding platform materials, approximately 25 million tons of soil are sent to landfill each year, sometimes at great cost, depending on its classification as landfill waste. Disposing of inert waste at a landfill can cost in the region of £25 per ton, with non-hazardous waste costing £100 per ton and hazardous waste exceeding hundreds of pounds per ton [33]. This scrap material is treated as if it were construction waste and is outside the scope of this research.

2.3. Advantages and Disadvantages

All previously reviewed uses (Table 3) have their own advantages and disadvantages. This needs to be considered when analysing the efficiency of each of these recycling and reuse options for all track waste materials. The major factors being addressed are the method of using and recycling the scrap track material. These various factors have been summarised into advantages and disadvantages. The authors have divided the categories into direct and indirect methods. The authors have also used references for providing possible ways of using these materials.

In the following section, the authors present an analysis of the carbon footprint left by track waste material in India at certain points during the transport and recycling processes. This calculation was estimated according to the cost and the carbon footprint left. The authors have analysed the cases for the direct and indirect use of recycling and obtained relevant conclusions.

These materials can be reused outside the railway sector, but the authors believe it is of greater overall benefit to try and use as much of the waste material as possible within the railway industry, thereby making both economic and environmental savings.

Table 4 shows a summary of the most important advantages and disadvantages of the direct and indirect uses of track waste material.

Table 3. Summary of direct and indirect uses of railway waste materials.

Track Elements	Types of Uses	
	Direct	**Indirect**
Rail	Dead-end railway structure Rail fencing Checkrail Guard rail Rail pegs Slope stabilisation, rail-driving Secondary tracks Manoeuvering tracks Parking tracks	Clad plate stainless steel by hot rolling Fly ash concrete additive Secondary steel Steel bars for construction
Fastenings	Secondary tracks	Steel bars for construction
Sleepers	Platform base for tracks (concrete) Information panels (steel, concrete) Marking railway boundaries (concrete, steel) Pathways (wood, concrete) Track blocks to keep rail distance from platform, under rail joints (wood) Fencing purposes (steel, wood, concrete) Slope stabilisation (wood, concrete) Other uses (park and garden furniture, stairs, tables, etc.) Housing	Recycled aggregate from concrete sleepers Aggregate used in polymer concrete Plastic sleepers Steel bars for construction
Ballast	Extra side space Rural pathways Cover for slab track sides	Discarded ballast for cement Slab track concrete additive

Table 4. Advantages and disadvantages of the different uses of railway scrap waste according to direct and indirect methods.

Type of Uses	Advantages	Disadvantages
Direct	– Directly for maintenance applied in places of operation. – The operating and fixing costs for direct uses are cheaper. – No manufacturing. – Cost-saving. – Environmentally friendly. CO_2 savings.	– Depending on the state of the scrap material, it needs continual maintenance (depending on the final purpose). – Additional maintenance can increase maintenance costs. – Previous analysis of the material is needed, depending on the final purpose; this means an increase in costs. Material classification according to purpose. Preliminary studies.
Indirect	– New developments and ways of treatment for scrap material from railways and other sources. – The material can be cast as required for various superstructures such as slab tracks, concrete structures, and others. – The process allows the material to be made into different shapes as required by its end use. – Ballast is mainly used in various other superstructures as these aggregates usually have greater strength than the normal coarse aggregates used in making concrete.	– Higher cost when material needs further processing – Increase in CO_2 emissions. Increased pollution. Decreased efficiency in recycling. – Secondary materials are more prone to failure. Further research is required for the final uses of these new materials. Additional analysis, lab tests, etc. – Structural properties are reduced, meaning in most cases, this material cannot be used for structural purposes. – Increased maintenance. For example, steel made from melted rails cannot be used in the structural work of buildings. It can only be used for boundary walls and single- or double-storey structures as an additional reinforcement material.

It is important to try to reuse material without making any significant changes to its properties in order to increase the efficiency of the recycling process. However, if there is no significant increase in the carbon footprint generated during the indirect processing of these materials then their use becomes feasible. The table presented above shows the various advantages and disadvantages related to the direct and indirect use of used track material along with the positive and negative impacts and the possible drawbacks appearing when these materials are used at rail yards and shunting points. The main advantage of their direct use is the money saved by not having to invest in new structural materials.

3. Methodology

In this section, the authors propose an analytical methodology for the secondary use of track waste materials considering the carbon footprint emissions and the total cost of the process (see Figure 17). Typically, attempts are made to recycle waste materials by using indirect methods, which in many cases means increased costs and an increased carbon footprint. In order to simplify the process and reuse the material in an environmentally friendly and economic way, the authors intend to analyse all the stages involved in the process by providing some study cases and would like to make several recommendations to save on both pollution and cost during the recycling and/or reusing processes.

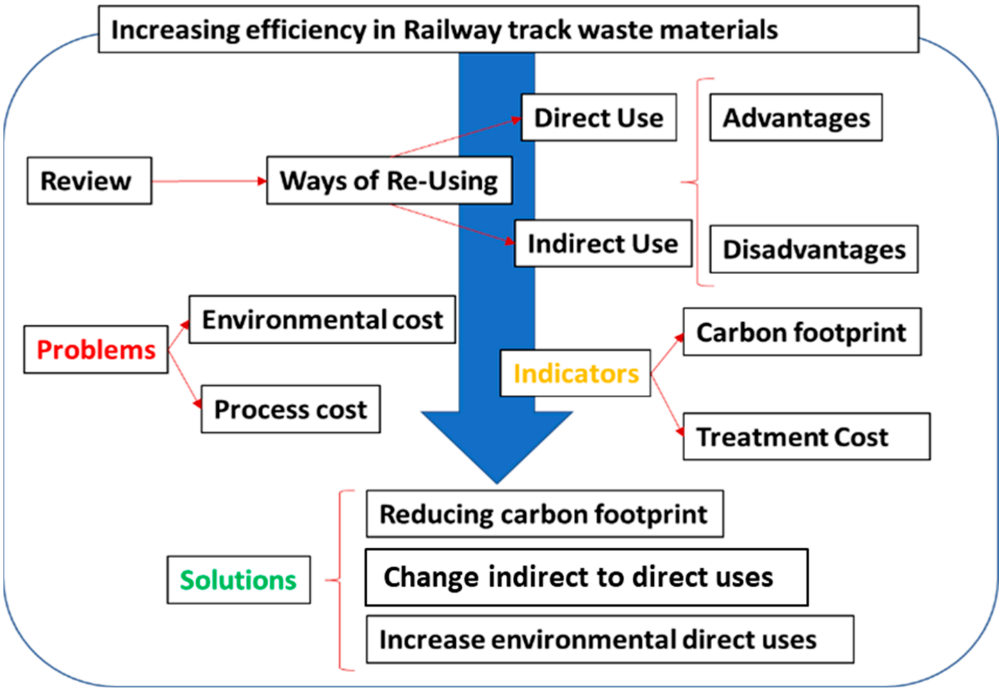

Figure 17. Methodology for increasing efficiency.

The first part of the methodology consists of looking at the different types of materials and the techniques available for reusing them, studying the advantages and disadvantages of the processes, then addressing their feasibility through some study cases and proposing some ways of reducing their carbon footprint by reducing indirect use and suggesting other new uses for these waste track materials.

Two main goals need to be considered: environmental efficiency (reducing the carbon footprint, reusing materials for environmental purposes) and reducing economic costs by reducing or eliminating indirect uses.

The most important secondary uses for these types of materials need to be reviewed. As previously mentioned, there are two main ways of reusing this material: (1) Direct use and (2) indirect use. A second opportunity can be given to these materials by reusing them within the railway industry or reusing them in other sectors.

The main concerns are environmental, as they represent high social costs. The authors propose using some indicators of the process in order to choose the most suitable solution for each material in each case. These indicators are related to the cost of the process from the beginning when the material is replaced to the end use of the new material. The steps involved in the process are presented in the following sections.

The scrap material needs to be classified. The material is classified according to the part or element taken from the track structure, rails, fastenings, sleepers, ballast, and sub-ballast.

The conditions and end use made of this used track material need to be understood as are crucial for any future use

The initial classification proposed by the authors is as follows: (1) good condition, if the material is in good condition and can generally be reused for direct use as it is; (2) acceptable, in this case, depending on the condition of the material, it could be used for direct or go directly to indirect uses; and (3) bad condition, in this case, the material needs to be transformed due to its low structural integrity or high material loss (high wear rate), which means that it can only be considered for indirect uses (Table 5).

This initial classification (Table 5) has been proposed according to the authors' experience. The material has to be in good condition (less than 1/3, in this case, the authors chose 30%) and the wear found on the material is $\frac{1}{4}$ of the total, which gives us 25%.

Table 5. Track waste classification proposed by the authors for secondary use.

Waste Track Material Classification		
1-Good Condition	**2-Acceptable**	**3-Bad Condition**
Direct Use Not contaminated Maintaining size No visible signs of wear	Direct/Indirect USE Partially contaminated (<50% total weight) Size altered by less than 30% Partial wear (less than 25% in volume)	Indirect Use Only Contaminated ($\geq$50% of total weight), smashed or crushed $\geq$30%, clear signs of wear, oxides More than 25% in volume.

These materials can be used on tracks or for other uses, indistinctly.

The next stage involves track scrap management. This part is essential. Here, railway engineers need to know the available options for this secondary use of track material.

As previously stated, this use of used track material has been divided into two parts: direct use, where the material is used directly with little or no maintenance in other areas of the railway superstructure, for example, guard rails, tongue rails, fencing, checkrails, rail pegs, etc. The fastenings such as fishplates can be reused in yard areas for rail joints and on secondary lines, where lower strength material can be reused. Lower quality ballast is reused in track alignment and for improving track stability. Sleepers are used on pathways and delimiting railway property.

Once the material has been classified, there are several options to choose from. The most suitable options for each material need to be analysed and several factors need to be considered:

- Condition of the waste material (evaluated as in Table 5).
- Availability for secondary uses. The new uses for this waste track material are often defined, so they need to be considered.
- Carbon footprint analysis. Here, the carbon footprint analysis needs to be calculated for all the available secondary uses in order to assess the environmental efficiency of the process.
- Material handling and treatment. This factor relates to how difficult the material is to handle. On some occasions, it is very difficult to reach the places and collect the materials.
- Proposing new uses for these waste materials. Environmental reasons are given priority over other issues.

The best solution is chosen after evaluating all the possible scenarios. Although the environmental aspects and costs are both important, the environmental reasons are chosen over the total costs involved in the process. The direct reuse of materials in activities close to the rail track is environmentally preferable due to the reduced transport costs and the processing costs associated with indirect uses.

The following section analyses a case study of direct and indirect uses for superstructure waste elements from a railway track.

Figure 18 shows a three-step approach to obtaining the best solution for these second-hand materials.

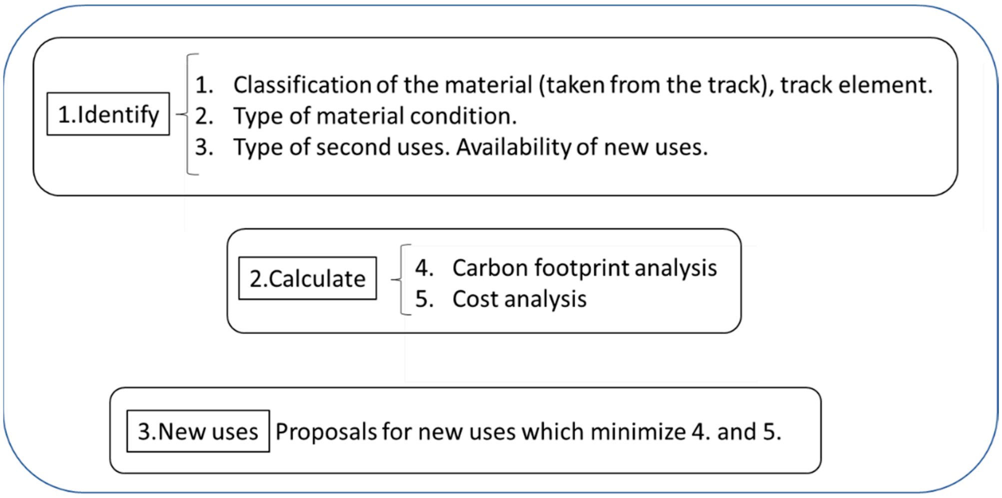

Figure 18. Proposal to increase the efficiency of the process.

The following section presents a case study applying this methodology.

4. An Indian Case Study to Improve Track Waste Efficiency

This section describes some case studies that follow the methodology proposed above. The authors calculate CO_2 emissions for both a direct and an indirect process by reusing track waste material (rails, sleepers, and ballast). The main interest is found in the carbon emissions generated by these operations. The estimated costs related to treatment and transportation are then calculated. The main objective is to reduce carbon emissions and improve the efficiency of the process.

Our concern is to find the carbon footprint generated by the indirect use of waste materials in the recycling process. From the methods studied in references [13–15,24–29], there was found to be a higher carbon footprint in the case of indirect uses because of the greater processing involved with this kind of recycling.

The authors use real examples found in India. In order to make an estimation and present a real case study, certain initial assumptions need to be made.

- The general costs used in the estimation are the real costs of energy in India (March 2021). Future analysis needs to be considered for revised costs.
- The fuel estimations and working hours used were taken from track works in India (March 2021), future performance will probably need corrections [34].
- The fuel consumption of track works machinery and transport trucks was obtained from [35].
- Transport using trucks has been considered for direct use [35].
- For indirect use, rubbish dumpers have been considered [35].
- Energy to process one ton of iron and one ton of ballast follows [36].
- The process begins when the material is taken from the track and ends where the material is in place at the destination (for direct use) or is transformed (indirect use).
- Transforming and manufacturing materials in the indirect processes were considered in the CO_2 estimation.

Table 6, below, summarises all the collected and estimated data required for the analysis.

Table 6. Data required for the analysis (Data from 2021).

General Cost in India	Numbers	Units	Considering Direct			Considering Indirect		
1 Gallon	3.78	litres	1 L truck	4.00	km	1 L dumper	6.00	km
1 h crane	4.50	litres				1 ton iron	700.00	kwh
1 L fuel	1.20	$				1 ton BALLAST	9.70	kwh
						1 KWH	0.14	

The examples used are two Indian railway lines. The line between Jhansi and Katni and the second line between Katni and Jabalpur (Figure 19).

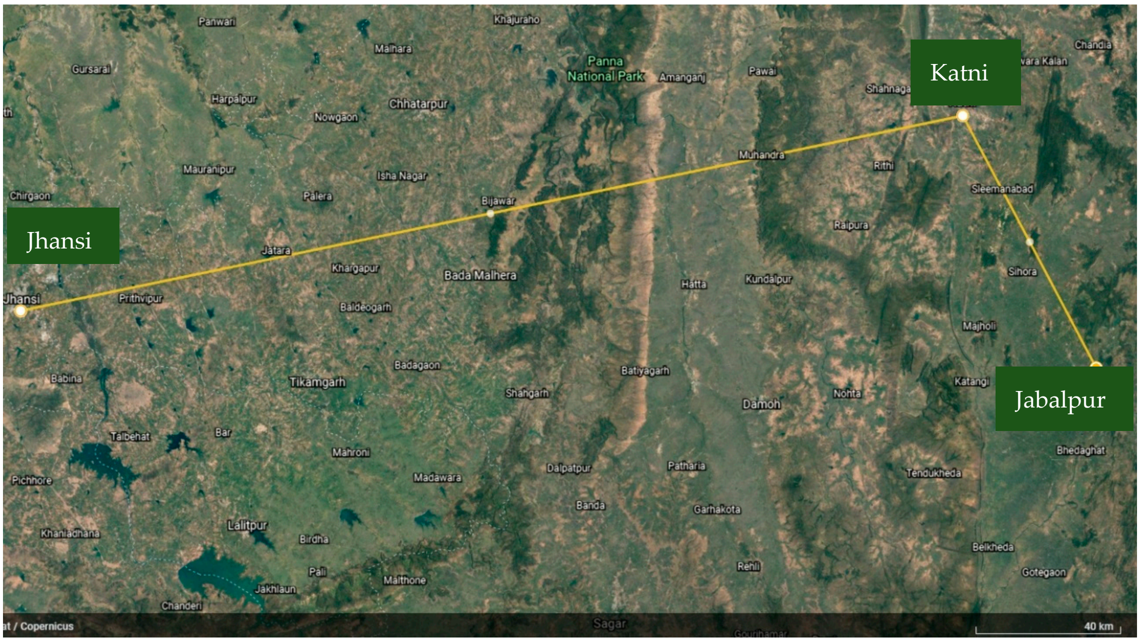

Figure 19. Cities of Janshi Uttar Pradesh, Katni Madhya Pradesh, and Jabalpur.

So, any comparisons are made under the same conditions and only picking/loading and storage/placement have been compared for both the direct and indirect processes (Figure 20, top). It has to be considered that the final transformation of the material generates an additional carbon footprint, as does transferring the material to its final destination (Figure 20, bottom).

The bibliography also provides some useful references for estimating the carbon footprint generated by the indirect process when transforming and manufacturing materials such as steel (rails and fastenings), concrete, cement, and ballast.

One of the most important findings in [37] is that the CO_2 emission for producing every ton of RC-450 CO_2 is around only 0.048 tons, for every ton of RC-800 CO_2 it is around 0.19 tons, and the average emission of 0.78 tons for OPC. RC-800 CO_2 showed a lower strength when compared with normal OPC.

An example of CO_2 production during the steel-making process can be found in [38]. The first thing to know is that CO_2 emissions depend on the process used to manufacture the steel.

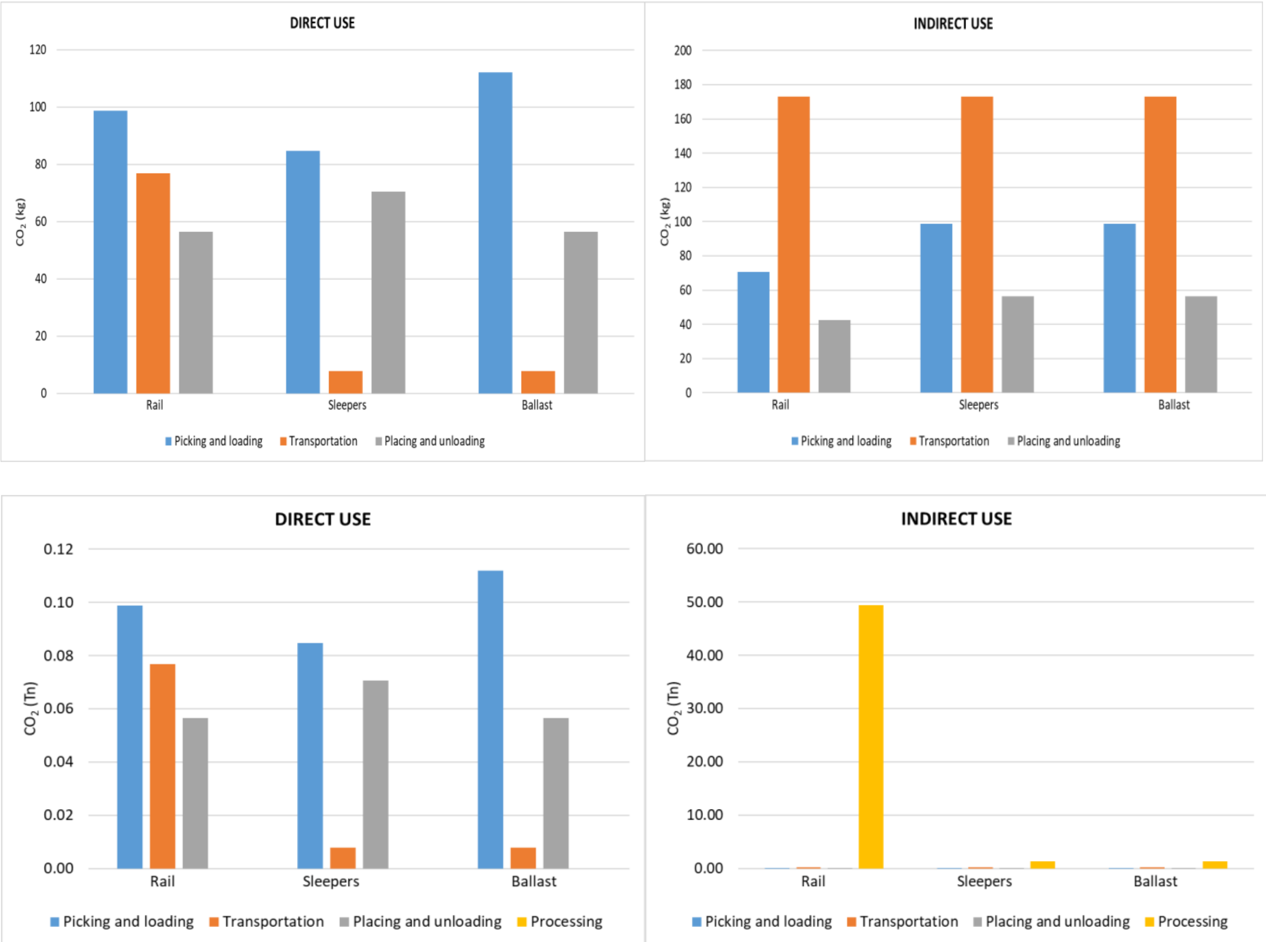

Figure 20. Comparison of different activities depending on the method used for waste track material. Without considering CO_2 emissions during the transformation of the initial materials (**top**) and considering the CO_2 emissions during the transformation of the initial materials (**bottom**).

The carbon footprint estimation was made in both cases by using data acquired from Table 6 and following the assumptions made in Section 4 for all the processes.

Four main phases were considered for the main materials taken from railway superstructures: rails, sleepers, and ballast. Taking the materials from the original site, transporting them from their origin to their destination (factory for transformation), unloading and storage, and finally the energy consumption during the final process: this gave us an amount of CO_2 generated.

The CO_2 emitted during transportation was calculated by taking the length of the shortest available route.

4.1. *Carbon Footprint Estimation for the Indirect Use of Rail, Sleepers and Ballast*

The first case study in the carbon footprint analysis for used rails is that of the Katni Madhya Pradesh line (India), where the rails are going to be transformed into a new material at the Janshi steel plant, Uttar Pradesh (India). In this case, the material has been classified as in bad condition (Table 5), which means that it is only required for indirect use.

In order to analyse this case, we need to know the distance between the origin (where it is taken from) and the destination (where is going to be transformed). There are three options: via Panna, via Hatta, or via Sagar. Via Panna is the shortest distance between Katni and Jashi.

The process has been divided into picking and loading at the origin, transportation to the destination, unloading, and finally processing (in this case smelting) into the final product (Table 7).

Table 7. Carbon footprint estimation for the indirect use of rail, sleepers, and ballast.

Carbon Footprint Estimation Indirect Use							
Type of Use	**Indirect**	**Distance**	**Picking and Loading**	**Transportation**	**Placing and Unloading**	**Processing**	**Total**
Track Element	**Energy Source**	**O-D (km)**	**Diesel**	**Diesel**	**Diesel**	**Electricity**	**Amount**
Rail	Amount of fuel (L)	331	27.00	55.17	13.50	70,000.00	70,095.67
	Cost of fuel ($)		32.40	66.20	16.20	10,000.00	10,114.80
	Time Taken (h)		6.00	7.30	3.00	5.00	21.30
	Carbon estimation (kg)		70.74	172.93	42.32	49,420.00	49,705.99
Sleepers	Amount of fuel (L)	331	22.50	55.17	11.25	1940.00	2028.92
	Cost of fuel ($)		27.00	66.20	13.50	277.14	383.84
	Time Taken (h)		5.00	7.30	2.50	6.00	20.80
	Carbon estimation (kg)		98.75	172.93	56.43	1369.64	1697.75
Ballast	Amount of fuel (L)	331	31.50	55.17	18.00	1940.00	2044.67
	Cost of fuel ($)		37.80	66.20	21.60	277.14	402.74
	Time Taken (h)		7.00	7.30	4.00	6.00	24.30
	Carbon estimation (kg)		98.75	172.93	56.43	1369.64	1697.75

Concrete sleepers can be reused by cleaning and then crushing them to obtain aggregate to make new concrete. The carbon footprint in the case of the indirect use of sleepers has been considered to be the same. The transported sleepers followed the same procedure, which can be seen in the flow diagram given below (Table 7). The same cities have been considered for the transportation routes.

The city chosen for the indirect use of this material has a concrete works, meaning it is feasible as a real example for the indirect use of this material.

The data in Tables 7 and 8 were calculated using the Indian Railways Track Maintenance System website. The information is highly confidential, and the researchers have worked very closely with Chief P. Way R.J Goswami [39], who oversees this division, to analyse it for this work. The data for all the materials used on the railways is taken from the TMS website. We decided to concentrate on the TMS data for the preceding year [29]. This work uses an authorised website to calculate the carbon footprint [24–26].

The material is taken from Katni-Murwara and is then transported to Jhansi (Figure 18).

Tables 7 and 8 show an example of the carbon footprint calculation for both direct and indirect uses. The O–D (Origin–Destination) column shows the distance in Km between the origin where the materials are taken to the final destination where they are stored or placed at their new location. The picking and loading column shows the CO_2 estimation during the removal of the material from the track. The transportation column represents the CO_2 involved during the transportation of the material. Placing and unloading relate to the CO_2 generated during the delivery of the material. The last column for processing shows the CO_2 emissions produced during the manufacturing of new material from the old material (indirect process).

The indirect process of creating a secondary use for track materials caused CO_2 emissions during the processing of these old materials into the new ones. The electricity consumed produces the highest amount of CO_2. This high amount of CO_2 generated by processing these materials can be significantly reduced by changing to direct use.

Transportation is the second activity that produces a lot of CO_2. By using these materials close to the initial place or even in the surrounding area, these emissions can also be reduced or even eliminated.

Table 8. Carbon footprint estimation for the direct use of rails, sleepers, and ballast.

Carbon Footprint Estimation Direct Use							
Type of Use Track Element	Direct Energy Source	Distance O-D (km)	Picking and Loading Diesel	Transportation Diesel	Placing and Unloading Diesel	Processing Electricity	Total Amount
Rail	Amount of fuel (L)	331	31.50	24.25	18.00		73.75
	Cost of fuel ($)		37.80	29.10	21.60		88.50
	Time Taken (h)		7.00	3.00	4.00		14.00
	Carbon estimation (kg)		98.75	76.81	56.43		231.99
Sleepers	Amount of fuel (L)	10	27.00	2.50	22.50		52.00
	Cost of fuel ($)		32.40	3.00	27.00		62.40
	Time Taken (h)		6.00	1.00	5.00		12.00
	Carbon estimation (kg)		84.64	7.84	70.54		163.02
Ballast	Amount of fuel (L)	10	36.00	2.50	18.00		56.50
	Cost of fuel ($)		43.20	3.00	21.60		67.80
	Time Taken (h)		8.00	1.00	4.00		13.00
	Carbon estimation (kg)		112.00	7.84	56.43		176.27

4.2. Carbon Footprint Analysis for Direct Use of Rail, Sleepers and Ballast

The case studies being presented have provided various examples of the direct reuse of used track materials. These are mostly used on the railways. Scrap material is classified as good condition or acceptable (Table 5). According to this classification, the material can be reused as road fill or for pathway construction. Ballast is not transported more than 10 km.

In the case of sleepers and ballast, these can be directly used for land delimitation or for making pathways or fencing (within 2 to 5 km). If the ballast is directly used for stabilising the sides of the track close to the source, then the carbon footprint is lowered (Table 8).

Ballast can be directly used in low-lying areas for composting with garbage. Organic garbage in India is usually directly dumped into contact with clay soils. This can be avoided by first placing a layer of scrap ballast above the clay soil and any anaerobic organic waste decomposition that occurs will stay on the layer of ballast. The clay soil is no longer in direct contact with the waste, so any deep penetration of the chemicals released during the decomposition of organic waste can be avoided along with changes in the organic properties of the clay soils. The carbon footprint is also reduced as the distance is short (not far away from the city, 10 km). The reason for the direct use of sleepers and ballast in nearby places is that the government does not want to invest in transport. Investing in transport for distant locations is not necessary when scrap material can be used in the surrounding areas near the railway track. As can be seen in Table 8, direct use involves little or no processing.

The authors would like to propose some alternatives in the following section for the reduction of these emissions and to simplify the whole process.

4.3. Analysis and Discussion

The process of recycling materials and reusing them gives a second opportunity to these used materials and provides economic and environmental benefits. Recycling is a process which is meant to look after the environment; however, sometimes this process is more expensive and not always environmentally friendly (due to the high carbon footprint).

Therefore, the authors have proposed a methodology to review and evaluate the secondary use of these materials to see if it is environmentally feasible to take advantage of them.

The previous figure shows the activities required to reuse waste track materials. Figure 20, above, does not show the CO_2 generated during the processing of materials (it is too high to be compared with the previous activities). This figure shows which activity per type of use generates the highest levels of CO_2.

For direct use, picking and loading produced the highest levels of CO_2, whereas, for indirect uses, transportation is the activity that generates the highest rates of CO_2 after processing.

The activities of picking and loading are difficult to improve. However, transportation can be reduced if the second use can take place close to the origin point of these materials (direct or indirect). It is difficult to reduce the CO_2 generated during the processing activities involved in indirect uses. The best way to improve this is by trying to find an alternative direct use for these materials at or close to their origin.

Figure 20, bottom, shows how processing the initial materials for new uses in the steel and concrete industries generates high amounts of CO_2. As can be seen in [37–39], the concrete cement and steel industries produce high amounts of CO_2 that can vary depending on the type of process, the materials, the temperature during the process, etc.

This work is only concerned with the processing of the materials shown in Table 9 and does not address any form of material fabrication, i.e., if rails are being studied, only the amount of material sold from Katni-Murwara is of interest [29], along with how much carbon is released during smelting, and the crushing of ballast and other materials described in this work. Certain questions were asked to the company that buys scrap material from this division, but these were confidential and the purpose of this research is to analyse carbon emissions without revealing the company [29].

Table 9. Summary of carbon footprint calculation for the direct and indirect uses of rails, sleepers, and ballast.

	Type of Uses	
Elements	**Direct**	**Indirect**
Rail	231.99	49,705.99
Sleepers	163.02	1697.75
Ballast	176.27	1697.75
Total, Carbon Footprint (kg)	571.28	53,101.5
Total, Cost (Dollars)	872.1	19,471.5

As can be seen in Table 9, the carbon footprint generated by the indirect process is almost a hundred times more than that of the direct process for reusing track materials. This means that finding activities for the direct use of these materials is by far the best way to improve the efficiency of the process.

In terms of the environment, the carbon footprint calculation is a requirement to explain how many kilograms of carbon are being produced by each stage of the process.

Economically, it is much cheaper to directly reuse railway scrap materials on the railways or in the surrounding areas than it is to send them for indirect uses, which cost more than double (Table 9).

5. Conclusions

The analysis presented in this paper has determined which activities in the recycling process generate high levels of CO_2 representing efficiency losses during the recycling process and higher economic and environmental costs. The results have confirmed that the processing activities performed during indirect uses generate the highest levels of CO_2. Treatment and transport also generate high rates of CO_2 emissions in both uses.

In view of the results, there are two ways of reducing these high rates of CO_2. One could be to simplify the processing activities in the industry, which means savings in time and money. Another way could be to give direct uses to these materials and reduce transport and treatment operations. Therefore, in order to increase efficiency, these materials need to be given an alternative direct use close to their place of origin. The authors have proposed several actions to reuse these track waste materials.

Ground instability problems near railway lines can cause serious derailments. Most of the problems associated with ground instability can be solved by using waste rails or used sleepers at or close to their origin. Driven rails for this purpose, or retaining walls made using concrete sleepers, can help to solve these problems.

This article has also presented an analysis of track scrap materials and the possibilities available to give them a second opportunity to be re-used. Different uses have been reviewed by analysing their advantages and disadvantages. Several case studies (for a real case in India) have been proposed and analysed. Results, as expected, give high levels of CO_2 for indirect uses (due to the final material transformation).

Environmental and geotechnical uses are the most suitable ways of reducing carbon footprint and CO_2 emissions.

Thanks to this analysis, the authors are able to make some useful recommendations in order to encourage railway administrators and companies to introduce new policies for the treatment and alternative uses for track waste and scrap materials from the railway industry.

This paper presents an initial methodology for categorising types of track waste materials and how they can be treated and sets out the basis for future and deeper research for each individual track material.

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