Master's Thesis

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Master Sustainable Business and Innovation

Environmental implications of zero-waste music festivals

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Author: Maria Bosser Carenys
Student ID: 6877788
Contact: m.bossercarenys@students.uu.nl

Supervisor: Dr. Ir. Jesús Rosales Carreón
Copernicus Institute, Utrecht University
Contact: j.rosalescarreon@uu.nl

Second reader: Dr. Ric Hoefnagels
Copernicus Institute, Utrecht University
Contact: r.hoefnagels@uu.nl

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LIST OF ABBREVIATIONS:

ARC	Agència de Residus de Catalunya (In English: Catalan Agency of Waste)
BAU	Business-As-Usual scenario
BYO	Bring Your Own
CE	Circular Economy
CF	Carbon Footprint
EF	Emission Factor
EOL	End-Of-Life
GHG	Greenhouse Gas
HDPE	High-density Polyethylene
IDEAL	Ideal scenario
LCA	Life Cycle Assessment
MBT	Mechanical-Biological Treatment plants
MFA	Material Flow Analysis
PET	Polyethylene Terephthalate
PLA	Polylactic Acid
PP	Polypropylene
RECY	Recycling scenario
REU	Reuse scenario
RQ	Research Question
SF	Substitution Factor
SORT	Sorting scenario
Sub-RQ	Sub Research Question
WF	Water Footprint
WMS	Waste Management System
ZWI	Zero Waste Index
ZWMS	Zero-Waste Management System

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Abstract

Music festivals can gravely impact the environment due to the large amounts of waste they produce. Waste from festivals is usually landfilled or incinerated. These end-of-life options are known to emit a lot of greenhouse gases and produce leachate, a liquid waste product that can heavily pollute groundwater and soil. Moreover, they contribute to resource depletion because the materials that end up dumped or burned can no longer be used, and more virgin material is needed to manufacture new products. This research evaluates the environmental implications of incorporating zero-waste measures in music festivals using case-study data from the festival Bioritme in Catalonia, Spain. The material flows of Bioritme were analyzed with a Material Flow Analysis (MFA), and the environmental impacts were assessed in terms of avoidance of virgin material extraction (with the Zero Waste Index (ZWI)), greenhouse gas emissions (with a Carbon Footprint), and water use (with a Water Footprint). Three scenarios were simulated with zero-waste measures that focused on higher recyclability, sorting, and reuse to compare their environmental performance with the business-as-usual scenario.

The findings suggest that the environmental impact of waste in music festivals can be minimized by switching to reusable products whenever possible and offering only highly recyclable disposables. Moreover, good sorting and the audience's active participation showed to be crucial for zero-waste measures to be successful. The results also revealed that the ZWI fails to address the benefits of waste avoidance, which can be solved by combining it with an MFA. Additionally, we found that a higher ZWI does not always translate into a better environmental performance: a high ZWI indicates low virgin material extraction, but the environmental impact of this extraction could still be very high. Pairing the ZWI with other relevant environmental indicators such as the Carbon and Water Footprints can address this limitation. Both the methodology and the findings of this study can be applied to other types of events that have control over the materials brought in and the waste collected, such as sports events or conferences.

1. Introduction

Music festivals as we know them today date back to 1954, to the Newport Jazz Festival's first edition (Chamberlain, 2017), but it was not until the late 60s when they started gaining significant popularity (Gajanan, 2019) . At that time, the "counter-culture" emerged in the US as a response to the political and social discomfort of the younger generation against the status-quo, standing for racial equality, women's rights, sexual liberation, artistic freedom, and love for nature (Evans & Kingsbury, 2009). In 1969 over 450,000 like-minded young adults attended the Woodstock Festival, "three days of peace and music", which popularized the counter-culture movement and portrayed music festivals as an ideal environment to challenge mainstream ways of life (Bennett, 2004; Evans & Kingsbury, 2009; Johnson, 2015).

Festivals have evolved from the communal, hippie spirit of Woodstock into what is said to be "one of the most exciting and fastest-growing forms of leisure, business, and tourism-related phenomena" (Getz, 1997, p.1). Before the COVID-19 pandemic, thousands of festivals took place every year in Europe (Cantor-Navas, 2020; Evenementen Toerisme Citymarketing, 2019; Lusk, 2018) and were an enhancer of the attendees' wellbeing and subjective happiness (Karlsen & Brändström, 2008; Matheson, 2008; Packer & Ballantyne, 2010), a fundamental pillar for artists' income and audience growth (Hargreaves Mclnytre & Jazz Development Trust, 2001), and for local economies to thrive (Blake, 1997; G. Hughes, 1999; Lee, 2008). Furthermore, despite commercialization, many festivals keep their cutting-edge essence and provide a space for behavioral change, challenging present political and environmental issues (Johnson, 2015; Sharpe, 2008).

Nonetheless, the popularity and size of music festivals today can also severely impact local communities and the environment (Mair & Laing, 2012). Overcrowding can pressure local infrastructure and congest roads (O'Rourke, Irwin, & Straker, 2011), disrupt the residents' lifestyles and businesses, and increase substance abuse, vandalism, and crime (Dwyer, Mellor, Mistilis, & Mules, 2000). Moreover, inflated prices can result in residents' exoduses (Dwyer et al., 2000), and local culture can end up deteriorating (Arcodia & Whitford, 2008). Emissions from audience traveling and power generation on-site contribute to global warming and air pollution. However, without accounting for externalities like audience traveling, the most significant contributor to the environmental impact of festivals is solid waste production (Andersson & Lundberg, 2013). In the UK alone, music festivals produce an estimated 23,500 tons of waste yearly, 68% of which is sent to landfill (Johnson, 2015), and the big American music festivals such as Coachella produce about 100 tons of waste on a daily basis (Meridian Consultants, 2016). The waste generated in music festivals is problematic for the nearby environment –contaminating water, soil, endangering fauna and flora, compromising public health, and increasing the chance of wildfires (Schultz, Bator, Large, Bruni, & Tabanico, 2013; Sjöström & Östblom, 2010)–, and beyond the boundaries of the festival –reducing landfill's lives, contributing to resource depletion and land-use change, and emitting GHG when decomposing (Tammemagi, 1999; Zaman & Lehmann, 2013). Just as important is the economic weight of festival site cleanups, which can skyrocket to hundreds of thousands of euros (ABC7 Chicago, 2019).

The zero-waste goal can serve as an "aspirational end process" (Cole, Osmani, Quddus, Wheatley, & Kay, 2014, p. 65) that music festivals can strive for in their battle against waste. Other sectors have been aiming for the zero-waste goal incentivized by higher land prices in urban areas (and hence higher landfill costs) due to population growth (A. Silva, Rosano, Stocker, & Gorissen, 2017) and the increasing environmental awareness over the take-make-dispose resource consumption pattern. The zero-waste goal consists of avoiding and eliminating waste by switching the perspective of "waste as a problem" to "waste as a valuable resource" (Di Leo & Salvia, 2017; Zaman & Swapan, 2016). In a zero-waste system, products are designed and managed so that all resources can be recovered from the waste stream, mimicking nature's processes (Fricker, 2003). For a music festival to achieve the zero-waste goal, it needs to switch its linear resource consumption pattern and end-of-pipe Waste Management System (WMS) to an all-encompassing one that considers product designers, manufacturers, retailers, waste collectors, sorters, and consumers. This holistic approach to waste management will seek to reuse, repair, sell or, as a last resort, recycle all the materials from the waste stream (Song, Li, & Zeng, 2015; Zaman & Lehmann, 2013).

This thesis is structured as follows: after a brief introduction, in Chapter 2, we define the research problem and introduce the research question and sub-questions. In Chapter 3, the theoretical foundation of the research is explained. Chapter 4 explains the proposed methodology, including data collection, analysis, and assumptions. The results are presented in Chapter 5 and discussed in Chapter 6, where we also reflect on the study's limitations and possible future research avenues. Chapter 7 rounds up the study with some concluding remarks.

2. Problem Definition

There is a conflict of ideas when it comes to music festivals and environmentalism. Historically, festivals have been the Mecca for hippie music lovers while at the same time contributing to a degradation of the natural environment that can extend beyond the boundaries of the festival site. The COVID-19 pandemic can be a blessing in disguise for the music festival industry: the pause in social gatherings provides the time to rethink and redesign how festivals are run, which was one of the main barriers against the greening of festivals (Mair & Laing, 2012). Moreover, organizers will need to take drastic measures for cost reduction if they want to survive the forecasted post-pandemic economic crisis. Working towards the zero-waste goal can minimize the impact of waste taxation (European Commission, 2014) and cleanup costs while serving as a marketing tool to attract an ever-growing environmentally-conscious audience.

This research aims at assessing the environmental implications of incorporating zero-waste measures in the Waste Management System (WMS) of music festivals. The Research Question (RQ) is:

"What are the environmental implications of incorporating zero-waste measures in the Waste Management System of music festivals?"

The following sub-RQ derive from it:

- *What are the characteristics of the Waste Management System of a music festival?*

In order to redesign the WMS of a festival, it is crucial to understand how it works. A WMS is generally bound to the characteristics of the waste stream it handles. Hence, finding new waste treatment measures also requires knowing the amount and type of waste the WMS handles, where it originates, and why.

- *What zero-waste measures can be incorporated in a Waste Management System?*

The zero-waste goal is very broad and can be pursued from multiple angles. Finding the zero-waste measures that fit best into a specific WMS require a deep understanding of what 'zero-waste' entails and of the needs and limitations of the WMS under study.

- *How can we evaluate the environmental impact of a Waste Management System?*

The environmental impacts of waste management practices need to be measurable if they are to be compared with alternatives. This evaluation must consider both the impacts avoided by managing the waste and the impacts caused by the WMS itself.

3. Theoretical Background

This chapter presents the background information necessary to set the foundation upon which the research is built. A conceptual framework links all the concepts introduced and summarizes the chapter in Section 3.5.

3.1 Music festivals

In this research, we define music festivals as temporal events that aim to entertain a limited number of attendees with live music performances, taking place within a delimited site, indoor, outdoor, urban, or rural. They can be broadly characterized into greenfield festivals (in outdoor rural areas, often with camping grounds) and venue-based festivals (indoor or outdoor urban venues). Music festivals can be conceptualized as systems. Systems are groups of interconnected elements that are organized to fulfill a function or to achieve a purpose. The elements of a festival are often tangible things (e.g., attendees, bars), the interconnections are the relationships that hold the elements together (e.g., bars provide beverages to the attendees), and the purpose determines the system's behavior (Meadows, 2008). The purpose of a music festival system is to entertain the audience through an immersive experience of continuous live music performances. By aiming at this, festivals bring several benefits to the community where they are organized. These benefits are discussed in greater detail in Section 3.1.1. Figure 1 shows a representation of the music festival system, its elements and interconnections, system boundaries, inputs, and outputs.

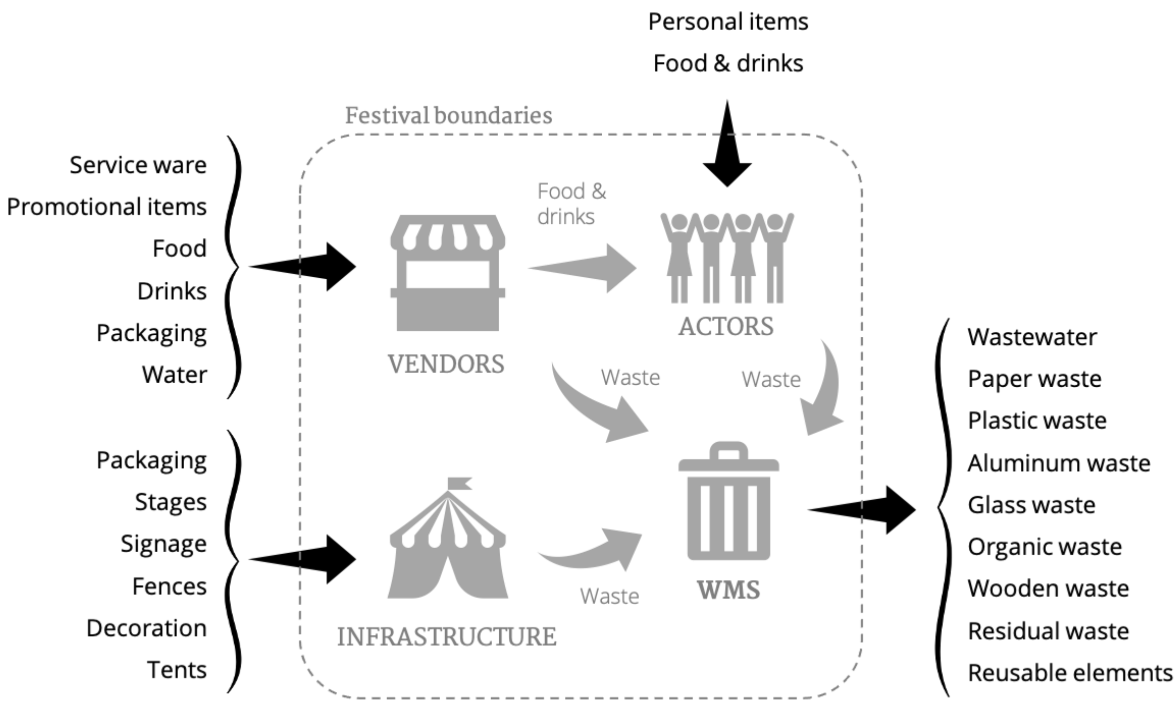

Figure 1: Music festival system.
Source: Own elaboration.

The elements that form the music festival system are the vendors, actors, site infrastructure, and Waste Management System (WMS). Vendors are the gates of consumer goods into the festival site, bringing in food, drinks, and other products such as cigarettes, glitter, or merchandise. These products are purchased by the actors of the festival (i.e., attendees, artists, and staff members), who either consume them (e.g., food, drinks), keep them (e.g., merchandise), litter, or dispose of them. The site infrastructure has the vital role of safely structuring and delimiting the site, staging the musical acts, and creating the distinctive atmosphere of the event. Some parts of the infrastructure are temporary and are used only for one edition (e.g., signage, decoration), while others can be reused from previous years or rented to third parties (e.g., stages, fences) (Metabolic, 2018; van de Voort & Schurink, 2018). The waste streams coming from the vendors, actors, and infrastructure are dealt with by the WMS of the festival. The WMS typically comprises sorting bins, a cleaning service for littered items, sanitation systems for human wastes (i.e., toilets, sinks, showers), and collection services that get the waste out of the site and bring it to the municipal waste system.

3.1.1 The pros and cons of music festivals

Music festivals are beneficial for several aspects of society and its economy: First, music festivals provide an environment for attendees to connect with each other, finding common grounds in a shared music taste. This has been found to positively affect people's mood, enhancing subjective happiness and a sense of community, identity, and social belonging (Karlsen & Brändström, 2008; Matheson, 2008; Packer & Ballantyne, 2010). Second, music festivals offer a platform for up-and-coming musicians and new music genres to grow their audiences (Hargreaves Mclnytre & Jazz Development Trust, 2001). Renowned festivals can act as music promoters in which the audience blindly trusts to broaden their music knowledge. Third, festivals are vehicles for celebrating local cultural identity (Blake, 1997), generating a community spirit brought about by common goals (Arcodia & Whitford, 2008), and internally enhancing the local community's image among residents and external visitors (Ward-Griffin, 2015). Last, this promotion can attract people to live in and visit the area (H. Hughes, 2000), sometimes expanding off-season tourism (G. Hughes, 1999), leading to higher employment in multiple sectors and, in some cases, better infrastructure (Lee, 2008).

Nevertheless, music festivals can be unsustainable and cause severe social, economic, and environmental problems. Overcrowding can pressure local infrastructure and congest roads (O'Rourke et al., 2011), disrupt the residents' lifestyles and businesses, and increase substance abuse, vandalism, and crime (Dwyer et al., 2000). Moreover, inflated prices can result in residents' exoduses (Dwyer et al., 2000), and overzealous attempts to commercialize local culture can end up deteriorating it (Arcodia & Whitford, 2008). Emissions from audience traveling and power generation on-site contribute to global warming and air pollution. Nearly 20,000 tons of CO_2 were emitted yearly by the music festival industry in the UK without accounting for audience traveling (Johnson, 2015), which is responsible for between 67-82% of the total emissions of each festival (Bottrill, Lye, Boykoff, & Liverman, 2008). Moreover, festivals usually rely on oversized diesel generators to run the show and ensure power continuity (Marchini, 2013). Oversizing the generators leads to low efficiency, shortening their lifespan, and burning more diesel (Kotriwala, 2017). Waste in festivals is also problematic for the environment. Leakages can contaminate the surrounding soil and freshwater, endangering fauna and flora, compromising public health, and increasing the chance of wildfires (Schultz et al., 2013; Sjöström & Östblom, 2010). Plus, large amounts of collected residual waste reduce landfill's lives, contribute to resource depletion and land-use change, emit GHG when decomposing, and pollute water and soil due to leachate (Tammemagi, 1999). The impacts of waste in festivals are further detailed in Section 3.2.1.

3.1.2 Waste in music festivals

Waste in music festivals is primarily composed of disposable products and food waste (Martinho et al., 2018; Metabolic, 2018; van de Voort & Schurink, 2018). Although many festivals provide sorting bins for separate waste collection, cross-contamination of waste streams and littering can happen (Cierjacks, Behr, & Kowarik, 2012; Zelenika, Moreau, & Zhao, 2018), meaning that organic and recyclables end up in the wrong bin and their value is lost. The main waste streams in festivals are explained below and summarized in Figure 2:

- **Organic waste** in festivals originates from food and drinks. Food and drinks are an essential part of the festival experience because, besides feeding the audience and staff, they can be a form of cultural expression of local gastronomy (Packer & Ballantyne, 2010), and are pivotal in many lifestyles and environmental movements such as veganism (Cherry, 2006), the Slow Food movement (Hjalager & Richards, 2002), or the Fair Trade movement (Moore, 2004).
- **Paper and plastic waste** in festivals primarily originate from food and drinks packaging and takeaway food and drinks containers (i.e., cups, service ware, water bottles, etc.). Packaging eases the transport of food and drinks and extends their shelf-life, which can reduce food and drink wastage (Zagory & Kader, 1988). Plastic and paper packaging have the added benefit of being lightweight and flexible, which reduces transportation costs and emissions (Andrady & Neal, 2009). The meals served in festivals generally come in disposable takeaway containers because they are cheap, easy to transport, and require no collection and cleaning after use.
- **Glass and aluminum waste** in festivals originate from bottles and cans for drinks. Glass bottles and aluminum cans protect drinks from chemical interactions, preserving taste and aroma (Glass Packaging Institute, n.d.; The Aluminum Association, n.d.).
- **Wooden waste** in festivals comes from infrastructural elements and decoration that cannot be used in future editions. These elements are responsible for building a safe and functional site while creating the trademark ambiance of the festival and determining the seamlessness of the experience.
- **Residual waste** in festivals comes from non-recyclable items brought by attendees and the festival (e.g., cigarette butts, bags of chips) and incorrectly disposed of recyclables and food.

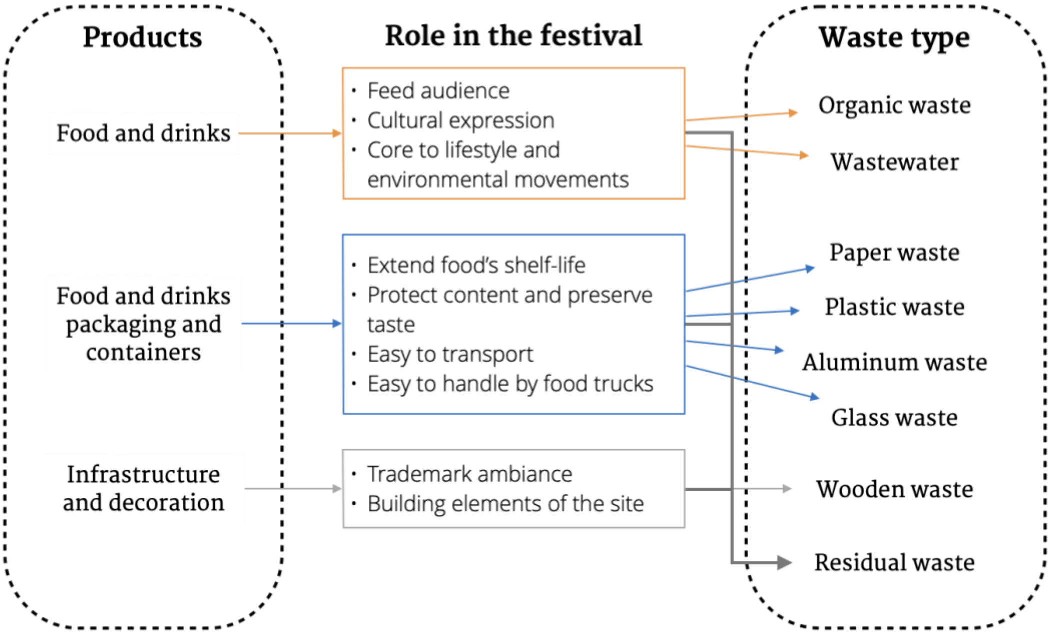

Figure 2: Products used and consumed in music festivals, their role, and the type of waste they become. Source: Own elaboration.

3.2 Zero-Waste

The zero-waste concept has been the object of study of many industry and academic papers (Hannon & Zaman, 2018). Among the various definitions found in literature, this research will use as a reference point the one proposed by the Zero Waste International Alliance (ZWIA) because it is the most broadly accepted and peer-reviewed one. They describe zero-waste as "the conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning and with no discharges to land, water, or air that threaten the environment or human health" (ZWIA, 2018).

The idea of zero-waste derives from the perception of waste as a valuable resource rather than a problem (Di Leo & Salvia, 2017; Hottle, Bilec, Brown, & Landis, 2015; Zaman, 2014; Zaman & Lehmann, 2013), reintroducing waste in the production process, and avoiding the negative impacts associated with material extraction and waste handling (Zaman & Lehmann, 2013). Zero-waste encompasses avoiding, reducing, reusing, redesigning, regenerating, recycling, repairing, remanufacturing, reselling, and re-distributing waste resources (Zaman & Lehmann, 2013). The holistic nature of zero-waste binds its performance to the active participation and collaboration of all the stakeholders: designers, manufacturers, retailers, collectors, sorters, and consumers (Clay, Gibson, & Ward, 2007). Still, behavioral and systemic changes surrounding waste are often challenging (Price, 2001) and require strong educational campaigns and clear waste management policies (Cole et al., 2014). Nevertheless, the zero-waste goal is simple and easy to convey, and its immutability (i.e., zero waste instead of waste reduction) makes it easy to target and allows flexibility in waste programs to adapt to each system's specificities (Tennant-Wood, 2003).

Zero-waste festivals can positively impact all three dimensions of sustainability: social, economic, and environmental (Pietzsch, Duarte Ribeiro, & Fleith De Medeiros, 2017). Zero-waste festivals have the potential of benefitting *society* by reducing people's exposure to hazardous materials, inspiring attendees to question their lifestyles and consumption patterns (O'Rourke et al., 2011; Săplăcan & Márton, 2019; Sussman, Greeno, Gifford, & Scannell, 2013), and increasing job offers for waste handling on- and off-site (Song et al., 2015; Zaman, 2015). From an *economic* point of view, achieving the zero-waste goal can reduce costs and increase the revenue streams of festivals. Although an initial investment is required, moving from single-use products to reusable ones can result in long-term cost reductions and avoidance of waste-associated taxes (Clay et al., 2007; Raw Foundation, 2018; van de Voort & Schurink, 2018) while selling recyclate and compost can add new revenue streams (Chang, Liu, Hung, Hu, & Chen, 2008). Moreover, communicating the zero-waste ambition will improve public opinion, giving a marketing advantage to the festival and possibly attracting bigger audiences (Mair & Laing, 2012). From an *environmental* point of view, zero-waste festivals can reduce the environmental impacts caused by waste disposal while also minimizing the need to extract virgin natural resources and their associated impacts.

3.2.1 Environmental impacts of waste in music festivals

This section identifies the environmental impacts of material extraction, manufacturing, and end-of-life of the main materials used in music festivals.

Food and drinks

The production of food and drinks has multiple environmental impacts, and their severity will depend on whether they are plant-based, seasonal, organic, and/or local. Emissions from livestock, fertilizers, and transport contribute to global warming and pollute the air, and the use of fertilizers can cause acidification and eutrophication of water and soil, harming ecosystems. Moreover, water use for irrigation contributes to water scarcity (85% of consumptive freshwater is destined to crops (Shiklomanov & Rodda, 2003)) and land-use change is causing deforestation and land degradation, further contributing to climate change (Eberle & Fels, 2016; Notarnicola, Tassielli, Renzulli, Castellani, & Sala, 2016; Pfister, Bayer, Koehler, & Hellweg, 2011).

When food and drinks are thrown away, they can be collected separately as organic waste. Organic waste can be brought to industrial composters or anaerobic digesters, where it decomposes into nutrient-rich soil. If the decomposition occurs in an anoxic environment (i.e., without oxygen) such as anaerobic digesters or landfills, the process emits biogas, a mixture of methane and carbon dioxide. Biogas is a potent GHG that can contribute significantly to global warming if released into the atmosphere, but it can also substitute natural gas when captured (Demirbas, 2011).

Paper

Virgin paper is mainly made with wood fibers, and paper companies are among the largest forest owners in the world. The environmental impacts of raw material extraction of wood for producing virgin paper are very similar to those of growing food (deforestation, water use, land-use change, GHG emissions). In addition, the wood fibers need to be processed to turn them into paper: first, wood is cut into small chips, and all non-cellulose components are removed with chemical processes, resulting in what is known as 'pulp'. To turn pulp into paper, it must be mixed with abundant water, chemically treated to reduce impurities, and finally dried with pressure and heat to produce paper (Bajpai, 2018). The pulp can also be made with recovered paper instead of virgin wood (i.e., paper recycling). Nonetheless, the whole process of manufacturing paper –either from wood or from paper– requires large amounts of water and is very energy-intensive. Moreover, virgin fibers are always necessary to strengthen the paper and neutralize quality degeneration (Laurijssen, Marsidi, Westenbroek, Worrell, & Faaij, 2010). If not recycled, paper will biodegrade (although slower than other organic waste).

Plastic

Almost all plastic products are made from fossil fuels. Their extraction has many environmental impacts: biodiversity loss due to habitat destruction (Butt et al., 2013), surface- and groundwater contamination (Allen, Cohen, Abelson, & Miller, 2012), and GHG emissions, to name a few. Crude oil and natural gas are refined and distilled, polymerized, molten, and turned into lentil-sized plastic pellets (Baheti, n.d.). These processes are very energy-intensive and emit GHG and pollutants to air and water. Plastic pellets can also be made from used plastic (mechanical recycling) or renewable sources (commonly referred to as bio-based plastics). Mechanical recycling consists in grounding plastic products, melting the pieces, and cutting the result into pellets (KIVO, n.d.). Bio-based plastics can be made by polymerizing renewable carbon sources from plants to produce plastic pellets. Bio-based plastics are gaining momentum, although not without skepticism about potential side-effects on food price increase, direct and indirect land-use change, and the impacts of agriculture (Gironi & Piemonte, 2011; Morão & de Bie, 2019). Different manufacturing techniques exist to turn pellets into products, the most popular being injection molding (heated plastic pressed into a cold mold), extrusion (heated plastic pressed through an opening and cut, similar to Playdoh), and blow molding (heated plastic is extruded, put into a mold, and pressed against its walls with compressed air) (Calovini, n.d.). These processes are energy-intensive because they require high heat and pressure.

Mechanically recycling plastic deteriorates the quality of the materials (Cossu, 2014; Haupt, Vadenbo, Zeltner, & Hellweg, 2017), and humans can be exposed to pollutants present in the waste (Pivnenko, Eriksen, Martín-Fernández, Eriksson, & Astrup, 2016; Pivnenko, Pedersen, Eriksson, & Astrup, 2015). The recycled pellets will need to be mixed with virgin plastic to diminish the change in properties (Hahladakis, Iacovidou, & Barcelo, 2018). Much attention is placed on chemical recycling, an innovative recycling process that breaks the material down to its building blocks so it can be polymerized again, maintaining the material's original quality (Ellen MacArthur Foundation, World Economic Forum, & McKinsey & Company, 2016). However, this technology is still not viable at scale, and the environmental impacts of the chemical processes could exceed its potential benefits (Rollinson & Oladejo, 2020). When plastic products end up in nature or landfills, they can remain in the environment for hundreds of years, only to break down into microplastics (Ellen MacArthur Foundation et al., 2016; Raw Foundation, 2018). Microplastics can be ingested by soil (Chae & An, 2018) and aquatic organisms (Vince & Hardesty, 2017) and climb up the food chain, severely affecting fauna in all trophic levels, including humans.

Aluminum

Aluminum is a high-barrier lightweight material that safely stores food and drinks and facilitates transport and storage (Luque-Calvo, Cerrillo-Gonzalez, Villen-Guzman, & Paz-Garcia, 2020). It is one of the most abundant metals on the Earth's crust, but extracting it from its ore requires enormous amounts of electricity, emits GHG, consumes high amounts of water, and has high freshwater eutrophication potential (Yang, Guo, Zhu, & Huang, 2019). To manufacture aluminum products, molten aluminum alloy is cast into primary ingots, flattened into paper-thin sheets, and cut and shaped into the final products (Hosford & Duncan, 1994). Aluminum scrap from manufacturing is molten again to form secondary ingots. Similarly, used aluminum products collected in the waste stream can also be molten and used for secondary ingots (after being cleaned from impurities). Primary (virgin) and secondary (recycled) aluminum ingots have the same quality, but recycled ones have significantly lower environmental impacts (Schlesinger, 2013).

Glass

Glass has been used for millennia as a high-barrier material to safely store food and drinks (among other purposes). It is made primarily from silica (sand), combined with soda and lime, three minerals that are abundant in nature (Moretti & Hreglich, 2013). To manufacture glass products, silica, soda, and lime are mixed and molten in furnaces until they have a honey-like consistency. The mix is poured into molds that shape the final product. The melting of the materials needs a lot of energy (furnaces reach temperatures over 1600ºC) and emits GHG (Vellini & Savioli, 2008). Instead of raw silica, soda, and lime, glass products can also be made from scrap glass from the waste stream, keeping the same quality. For this, scrap glass is crushed, cleaned of impurities, and molten into the honey-like feedstock. Using recycled glass in the feedstock reduces the furnace's energy use and emissions (Larsen, Merrild, & Christensen, 2009).

Wood

Wood in festivals is generally used in the form of pallets. To make new pallets, hardwood trees are cut and the logs are transported to mills, which turn them into wood products from which the pallets are assembled (Carrano & Thorn, 2014). The environmental impacts of raw material extraction are the same as for producing virgin paper (deforestation, water use, land-use change, GHG emissions). Cutting and drying the wood in mills before assembly are the most energy-intensive processes of pallet manufacturing (Bergman & Bowe, 2008). By refurbishing and recycling pallets, most of the environmental impacts of raw material extraction and manufacture can be avoided. It is estimated that one in four pallets in circulation is already refurbished (Araman, Bush, Hammett, & Hager, 1998) and that about 87% of the wood from pallets received for recycling is used again in a pallet (Bush, Reddy, & Araman, 1996). When a pallet is damaged beyond repair or its parts cannot be used in other pallets, it can be mulched for other purposes (e.g., poultry litter, livestock bedding) or incinerated for energy recovery (Carrano & Thorn, 2014).

Residual waste

Residual waste is treated differently in every country. Some countries like the US, with many uninhabited lands available, put most of their residual waste in landfills. Landfills are tightly sealed containers engineered to minimize the impact of waste on the environment (Demirbas, 2011). However, when rain passes through a landfill site, it can be contaminated by the liquids generated by the breakdown of the waste and contaminate groundwater and aquatic ecosystems, which is known as “leaching” (Wiszniowski, Robert, Surmacz-Gorska, Miksch, & Weber, 2006). Densely populated countries like the Netherlands burn their residual waste to produce energy before landfilling it. Waste incineration reduces the volume and mass of solid waste (Cobo, Dominguez-Ramos, & Irabien, 2018) and has the added benefit of producing heat and electricity, potentially displacing conventional energy sources (Boesch, Vadenbo, Saner, Huter, & Hellweg, 2014). Nevertheless, burning waste emits GHG, and the landfilled ashes contain leachable and highly polluting heavy metals (Assi et al., 2020).

3.3 Waste Management Systems

Waste Management Systems (WMS) are the systems responsible for removing waste from its source and safely handling it. They typically comprise collecting, transportation, sorting, processing, recycling, incinerating, disposal, and monitoring waste materials (Demirbas, 2011). Traditionally, these systems are designed as "end-of-pipe" solutions in a linear economy where waste is considered an "end-of-life" product. WMS are reigned by the waste management hierarchy (Figure 3), a step-by-step ladder that prioritizes actions to reduce and manage waste, aiming to protect the environment, conserve resources, and minimize waste generation (Williams, 2015). The waste management hierarchy says that a sustainable WMS must intend to minimize operations that use too many raw materials and energy (unless they yield an overall environmental advantage), maximize material recovery, maximize energy recovery when material recovery is not an option, and minimize landfilling (Arena & Di Gregorio, 2014). Nonetheless, only 11% of the global collected waste is recycled, and 19% is incinerated for electricity production (Chalmin & Gaillochet, 2009).

Figure 3: Waste management hierarchy.
Source: European Commission (n.d.).

Preventing waste calls for a change in the perception of waste as an "end-of-life" product. Instead, waste should be seen as a product in the intermediate phase of resource consumption (Zaman, 2015). Zero-Waste Management Systems (ZWMS) take a holistic approach to waste management and focus on the entire life cycle of products, including design, disassembly, inspection, reassembly, and elimination of toxic chemicals (Singh & Ordoñez, 2016), and give equal importance to all actors of the system (i.e., waste managers, consumers, and supply chains) (Clay et al., 2007). Figure 4 shows a conventional WMS in gray and a ZWMS in black. ZWMS expand conventional WMS's boundaries to account for the consequences of closing material loops by including the transformation of raw materials into waste in the system. Ideally, ZWMS manage mixed solid waste to deliver materials, nutrients, and energy. Nonetheless, landfills are not fully replaceable because some waste is impossible to valorize with current technologies (Cobo et al., 2018; Zaman, 2015).

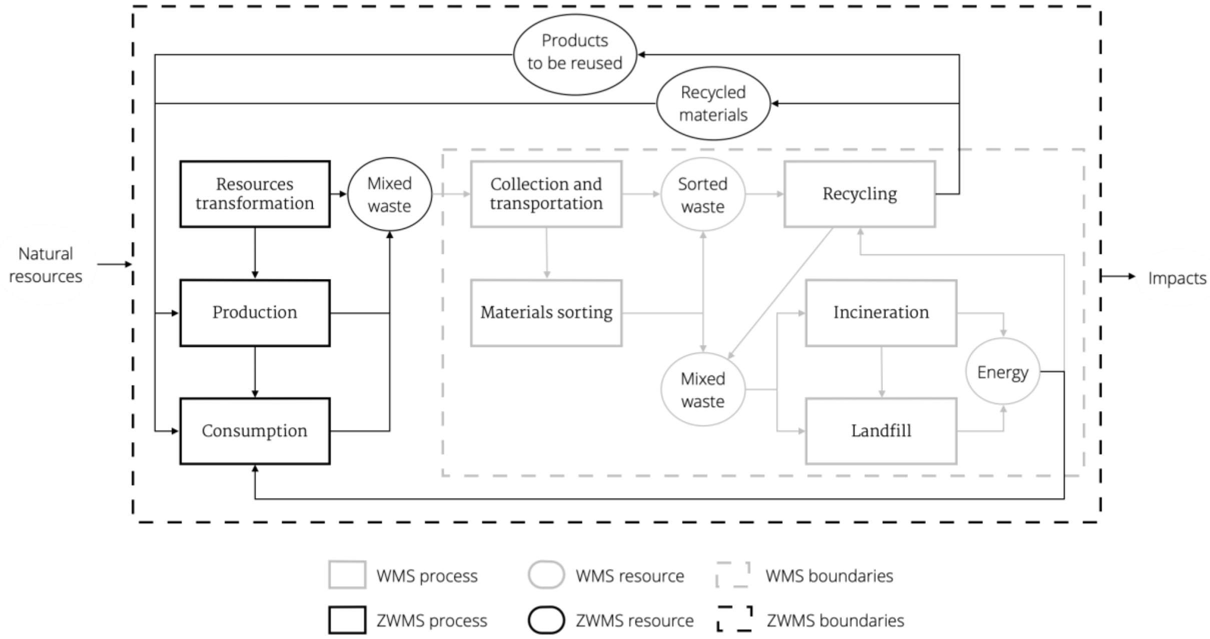

Figure 4: Configuration and boundaries of a ZWMS.
Source: Own elaboration, derived from Cobo et al. (2018).

The control music festivals have over what goes in –and therefore, what goes out– of their physical boundaries, makes them ideal for implementing a ZWMS by incorporating zero-waste measures. Festival organizers can influence most of the elements of a ZWMS: product design, waste collection, sorting, material upgrading, energy recovery mechanisms, and even consumer behavior. Organizers can ban certain materials or toxic components from being sold on-site and impose the use of products and infrastructural elements designed for disassembly, cleaning, and reassembly for reuse (Hottle et al., 2015; Metabolic, 2018; van de Voort & Schurink, 2018). Moreover, waste collection can be designed in such a way that areas and phases with high attendee density (i.e., number of people per surface area) and high consumption levels receive special attention to reduce littering and facilitate material sorting (Cierjacks et al., 2012; Ghinea et al., 2016). Additionally, the attendees' actions can be shaped with communication schemes before and during the event, clear signage about waste management, and staffed information points to convey what is expected from them (Cierjacks et al., 2012; Sussman et al., 2013; van de Voort & Schurink, 2018; Zelenika et al., 2018).

Figure 5 illustrates the environmental impacts of three WMS with different end-of-life measures. The size of the icons and arrows indicates the severity of the impacts. Figure 5 (a) illustrates the linear make-use-dispose system where waste goes directly to landfills or incineration. In this system, each life cycle phase and its associated environmental impacts occur every time a product is used. Figure 5 (b) illustrates a WMS with a recycling system. Here, materials are used again to manufacture new products, reducing the impacts of raw material extraction. Some material losses occur in the recycling process (secondary losses), and thus landfills and incineration are not entirely avoided. Figure 5 (c) illustrates a WMS with a reuse system. Here, there is no landfill or incineration because the whole product is used again without secondary losses. Material extraction and manufacturing impacts are less than in the other two systems because they only occur once for as many uses as the product has.

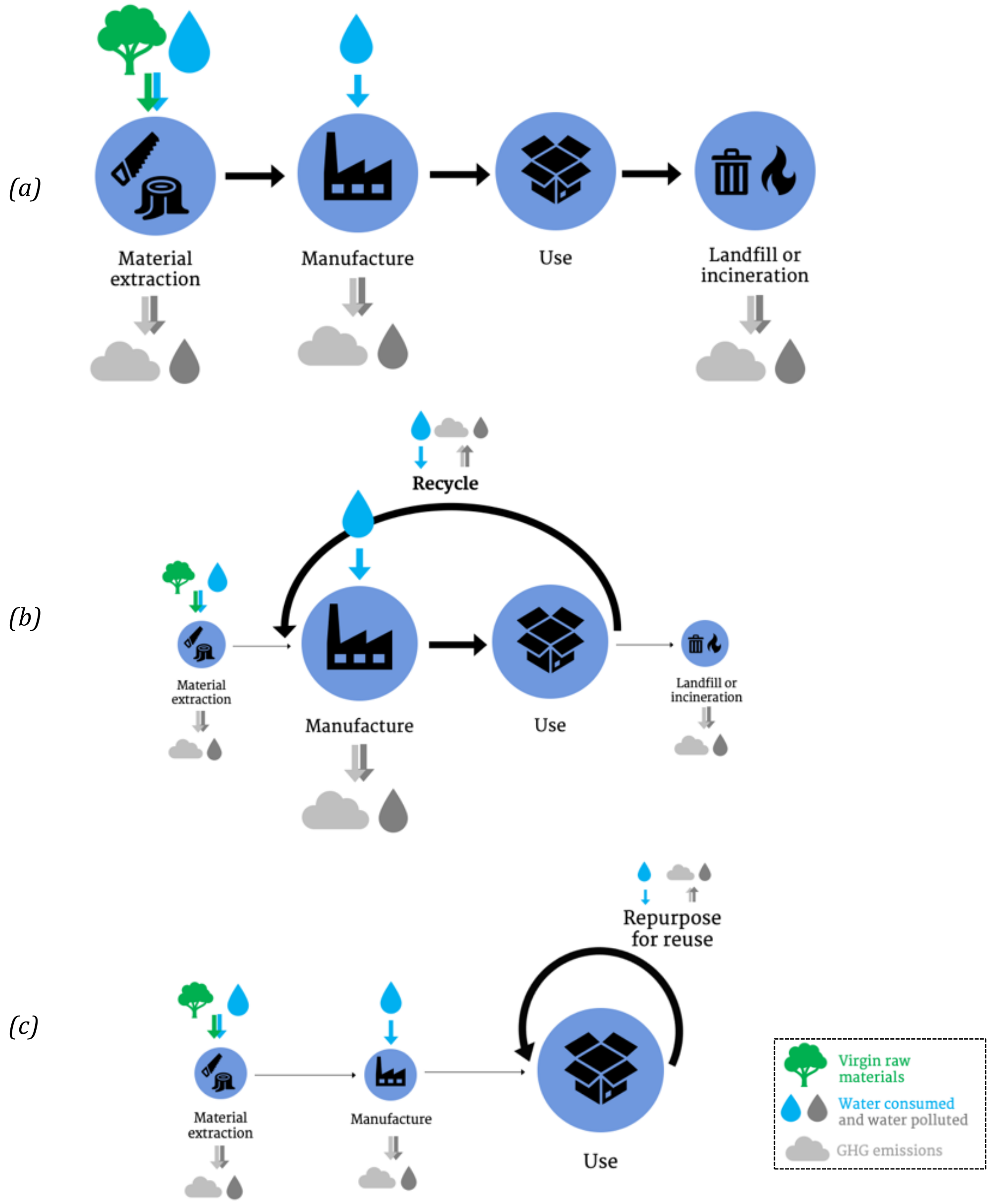

Figure 5: Virgin resource use, water use, and emissions in the life cycle of a product (excl. transportation) in different WMS: (a) linear make-use-dispose, (b) recycle, (c) reuse.
Source: Own elaboration.

3.4 Environmental performance assessment of Waste Management Systems

The performance evaluation of WMS in this research is done from an environmental standpoint. As discussed in Section 3.2, zero-waste is defined as "the conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning and with no discharges to land, water, or air that threaten the environment or human health". Hence, successful zero-waste initiatives reduce the environmental impacts of waste by minimizing (1) waste discharges and (2) resource extraction. Tools like the Life Cycle Assessment and Material Flow Analysis are widely used to study the impacts, inputs, and outputs of systems, products, and services. When evaluating the environmental performance of ZWMS, these tools can be combined with indicators that assess the impacts of waste discharges (Waste Diversion Rate, Zero-Waste Index), the avoidance of virgin material extraction (Zero-Waste Index), renewable resource degradation (Ecological Footprint), GHG emissions (Carbon Footprint), and water use (Water Footprint).

The **Life Cycle Assessment (LCA)** is a tool that assesses the environmental impacts of a product or service at every stage of its life cycle (raw material acquisition, production, use, and disposal) (ISO 14040, 2006). Several environmental impact categories can be studied in an LCA: acidification, resource depletion, ozone depletion, ecotoxicity, eutrophication, photochemical ozone formation, climate change, biodiversity loss, human toxicity, water use, and land use (UNEP, 2011). However, LCA is a cradle-to-grave analysis and therefore only focuses on the end-of-pipe consequences of waste. The performance evaluation of zero-waste initiatives calls for an assessment criterion that accounts for the offsets of substituting virgin materials with WMS initiatives.

The **Material Flow Analysis (MFA)** is an analytical tool based on the mass balance that assesses the flows and stocks of materials in a system. It explains a system's metabolism by linking processes and activities with material inputs and outputs, allowing to see the materials' importance in the system and whether they could be a resource (Brunner & Rechberger, 2004; Hendriks et al., 2000). The Dutch music festival DGTL has used this tool to become the first fully circular music festival in the world (Metabolic, 2018). However, an MFA alone cannot evaluate the environmental consequences of a system's material flows, and it needs to be combined with a follow-up environmental evaluation (García-Guaita, González-García, Villanueva-Rey, Moreira, & Feijoo, 2018).

The **Waste Diversion Rate** is an indicator that measures the percentage of total waste that is diverted from landfills and incineration by being reduced, reused, recycled, and composted (CalRecycle, 2020). It is used to measure the performance of municipal WMS worldwide (Zaman & Lehmann, 2013). However, it only tackles waste discharge and does not address the issue of resource extraction (Marpman, 2011), making it unsuitable for zero-waste evaluation.

The **Zero-Waste Index (ZWI)** is an indicator that evaluates the environmental impacts of a WMS, considering the waste that it avoids and the virgin resources that the WMS offsets. It assumes that the recovered materials from waste avoid the extraction of the same amount of virgin materials (Zaman & Lehmann, 2013). However, since the index only focuses on virgin material substitution, it cannot capture the benefits of waste reduction and avoidance.

The **Footprint Family**, as defined by Galli et al. (2012), is a "set of indicators able to track human pressure on the surrounding environment, where pressure is defined as the appropriation of biological natural resources and CO_2 uptake, emission of GHG, and consumption and pollution of global freshwater resources" (Galli et al., 2012, p. 103). The biosphere, atmosphere, and hydrosphere are monitored through the combination of the Ecological, Carbon, and Water Footprints, respectively. These indicators can be used to measure WMS:

- **Ecological Footprint**: indicator that measures the human appropriation of the Earth's regenerative capacity, expressed in units of world average bioproductive area: global hectares (gha). The Ecological Footprint focuses on the human demands for renewable resources and CO_2 assimilation and compares them with the planet's ecological assets (Monfreda, Wackernagel, & Deumling, 2004). Six ecosystem services are tracked and associated with a type of bioproductive land: plant-based products (cropland); animal products (cropland and grazing land); fish-based products (fishing grounds); timber and other forest products (forest); absorption of fossil dioxide emissions (carbon uptake land); and provision of physical space for shelter and other infrastructure (built-up area) (Galli et al., 2012).
- **Carbon Footprint** (CF): indicator that measures the GHG emissions caused by resource-consumption activities, expressed in kg of CO_2 equivalent (kgCO_2eq). It considers the direct (on-site, internal) and indirect (off-site, external, upstream, downstream) emissions accumulated over the life of an activity or product. The CF is one of the most popular indicators to assess sustainable development (Robinson et al., 2006) because of the growing awareness of the dangers of global warming.
- **Water Footprint** (WF): indicator that measures the water volumes used to produce goods and services (Hoekstra & Chapagain, 2011). It has three main components: blue WF (consumption of surface and groundwater), green WF (consumption of rainwater stored in the soil as soil moisture), and gray WF (water needed to assimilate the pollution from services and the production of goods, based on existing water quality standards) (Hoekstra, 2009). The WF is expressed in water volumes consumed (i.e., evaporated or incorporated) and polluted per unit of time.

The following section summarizes all the theoretical concepts introduced, explaining how each of them plays a role in achieving the goal of the research and their interconnections.

3.5 Conceptual Framework

The conceptual framework presented in Figure 6 summarizes the theoretical context within which this research is conducted. Our aim is to find the environmental implications of incorporating zero-waste measures in the Waste Management System (WMS) of a music festival. Changing the WMS of a festival requires, first, defining the music festival system and the type of waste that it generates (Section 3.1). It is crucial to know which products penetrate the boundaries of the festival system, the role they play in it, and the type of waste they create. Knowing each product's role is essential to ensure that any alternatives introduced still fulfill all the necessary functionalities. Second, we must understand what the zero-waste concept entails (Section 3.2), how a festival's WMS must change to incorporate zero-waste practices, and the environmental impacts avoided with zero-waste festivals (Section 3.2.1). Last, a performance assessment method that can measure the environmental benefits (or avoided impacts) of a WMS is necessary to understand the environmental implications of a zero-waste music festival (Section 3.4).

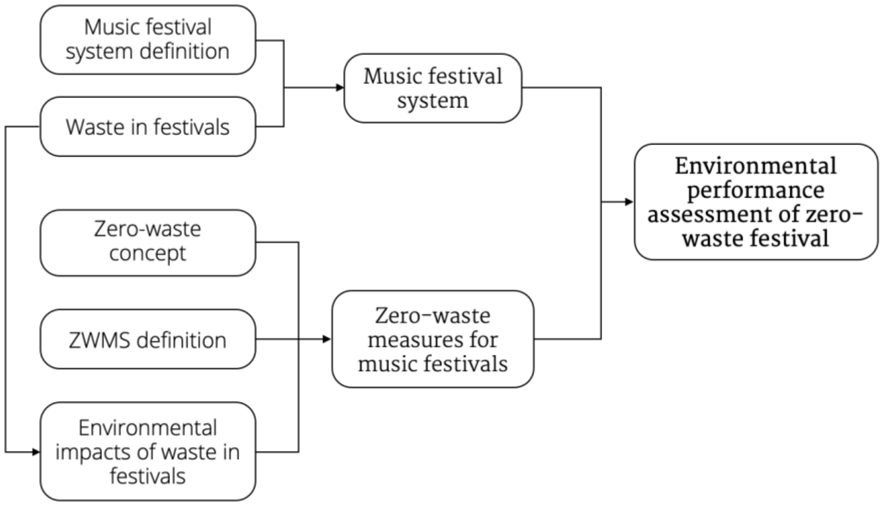

Figure 6: Conceptual framework of this research.
Source: Own elaboration.

In the next chapter, we present how the research was conducted, including the research structure, data sources, and data collection and analysis methods.

4. Methodology

This chapter presents the methods followed to answer the research question. The research design consists of a mix of quantitative methods conducted on the case study festival Bioritme, introduced in Section 4.1. Figure 7 shows the structure of the research, divided into three phases and their respective data collection, data analysis, and outcomes. We developed a model for the calculations of all the research phases using Microsoft Excel; its user interface is presented in Appendix D.

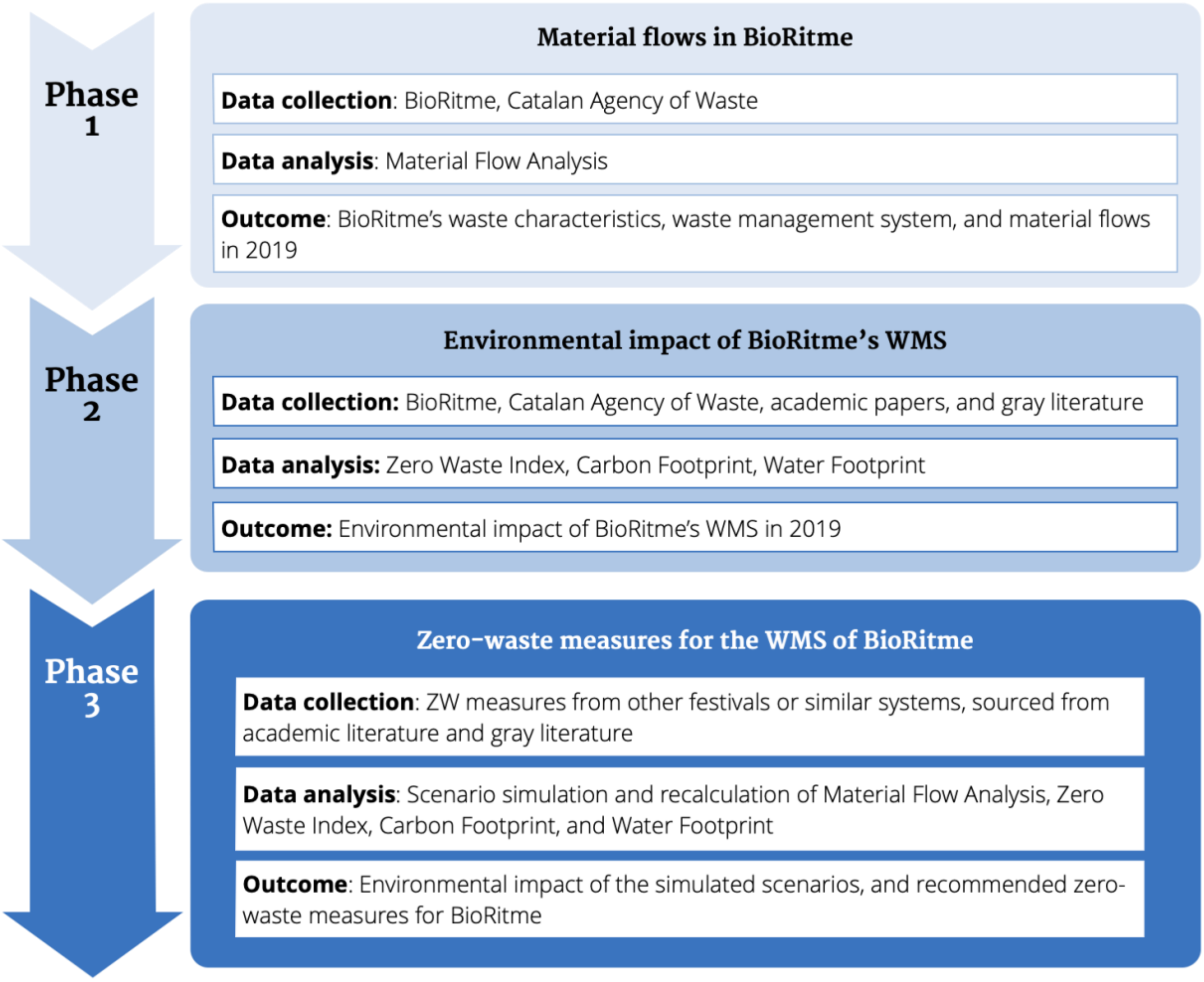

Figure 7: Research methodology phases, their respective data collection and analysis methods, and outcomes. Source: Own elaboration.

4.1 Case study festival

Case-study applied research on zero-waste practices has been recommended by Pietzsch et al. (2017), as it has the potential to relate the benefits, challenges, and critical success factors with reality. To study the environmental implications of incorporating zero-waste measures in music festivals, we selected the festival Bioritme (https://Bioritmefestival.org/) as our case study, focusing on the last edition before the COVID-19 pandemic, in 2019. Bioritme is a 4-day greenfield music festival that hosted 4800 attendees (i.e., those who paid for entrance) and 563 volunteers, staff, and artists in 2019. The audience is very young, with 50% of attendees being under 25, 30% between 25-30, and 20% families with kids. Bioritme takes place in a rural environment next to the emblematic location of the Sau Reservoir, 100km north of Barcelona (Figure 8 left). The Sau Reservoir is in the protected natural environment of Guilleries-Savassona, in the region of Osona in Catalonia. It is surrounded by forests and is home to many terrestrial and riparian species (Parcs i Pobles de Catalunya, 2019). The reservoir was built on the Ter River in 1962 for a hydropower station, covering the village of Sant Romà. Nowadays, the bell tower of the old church emerges from the reservoir when the water is low (Figure 8 right), attracting many visitors (Catalunya Turisme, n.d.).

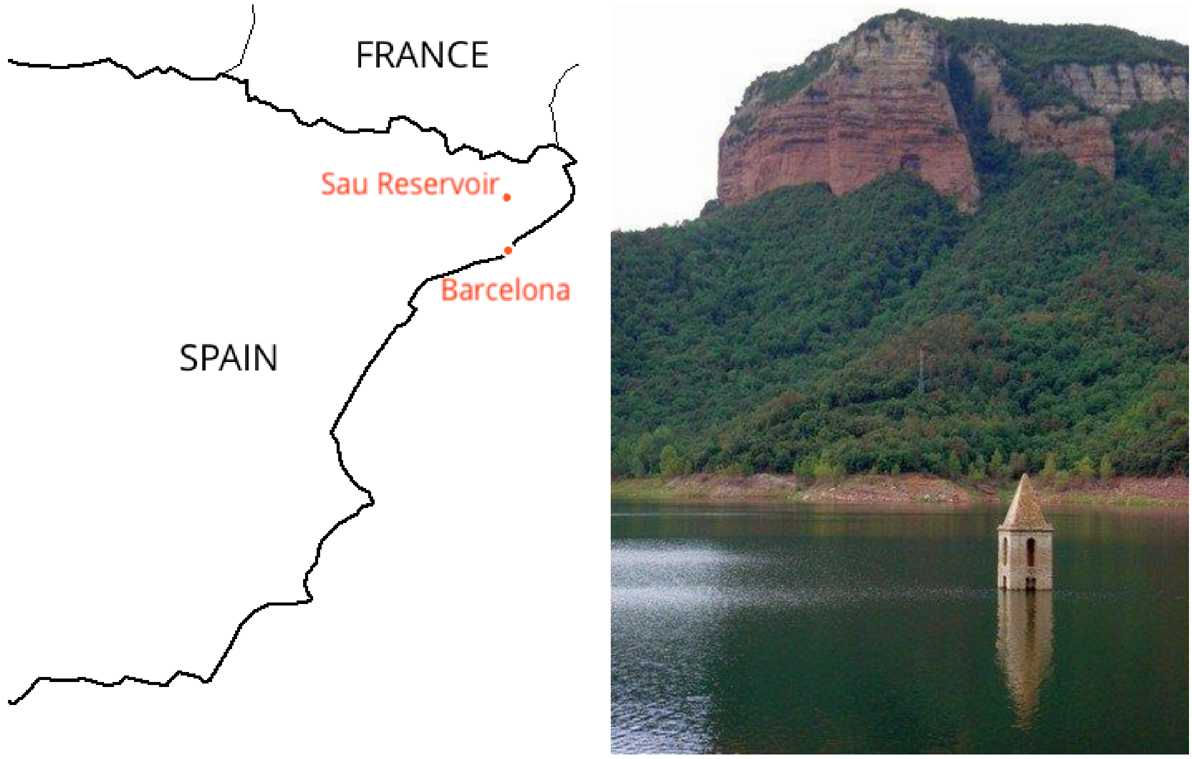

Figure 8: Location of the Sau Reservoir (left) and the emblematic bell tower of Sant Romà (right)
Source: Own elaboration (left), Posthums (2012) (right)

In this unique environment, Bioritme embraces the responsibility of protecting its surroundings and places ecology as one of its main pillars of the festival[1] (Bioritme, 2018a). Additionally, Bioritme claims to be "much more than a music festival" (Bioritme, 2018b, para. 1) and provides a space where social and political constructs are questioned through music, art, workshops, and talks (Bioritme, 2018a). The festival is organized almost entirely by volunteers, and they aim at making the festival as sustainable as possible:

- All food sold on-site is organic and locally sourced, served in paper plates and compostable plastic cutlery. Moreover, Bioritme allows the audience to bring their own food from home and cook on the camping grounds.

[1] The name "Bioritme" literally translates to "BioRhythm"

- Cold drinks are served in reusable (but non-returnable) hard plastic cups.
- Plastic bags and cardboard containers are distributed across the site and backstage for the separate collection of lightweight packaging (including plastic and aluminum packaging), paper and cardboard, glass, organic waste, and residual waste. The municipal WMS of Osona picks up the trash and brings it to their corresponding treatment plants: lightweight packaging, paper, and glass go to recycling plants, organic waste goes to industrial composting facilities or anaerobic digesters, and residual waste goes to mechanical-biological treatment plants (MBT) (ARC, 2019). MBT plants recover some recyclable materials from residual waste, produce compost, and stabilize the rest before landfill and incineration.
- Over 90% of the toilets on-site are dry toilets. These toilets need no water, chemicals, or energy, and the end product may be applied to improve soil conditions (Natural Event, n.d.).
- The water used for non-drinking purposes (e.g., showering, washing dishes) is treated water from the Sau reservoir. The wastewater from showers and sinks is treated again and released back into the reservoir, closing the water loop.

4.2 Phase 1: Material flows in Bioritme

In the first phase of the research, we analyzed the flows of materials entering and leaving the festival's boundaries with a Material Flow Analysis (MFA). The MFA is a tool that analyzes the flows and stocks of materials in a system with defined temporal and spatial scope (Brunner & Rechberger, 2004). It is based on the mass balance, meaning that the sum of all inputs must be equal to all the outputs plus stock changes. The temporal scope of the MFA was between 22nd and 25th August 2019 (dates excluding preparation and dismantling of the site), and the spatial scope was the physical boundaries of the festival site. The materials under study were paper, plastic, aluminum, glass, organic, wood, and rest.

Figure 9 illustrates the materials flowing in the festival. The inputs are the sum of items brought by attendees and items brought by the festival. Examples of items brought by attendees can be cigarettes, camping gear, or food packaging. The items brought by the festival can be classified into items that were sold to attendees (e.g., water bottles) and items reused either from previous editions (e.g., signage) or rented from third parties (e.g., stages). The outputs are the sum of waste and reusable items. Waste can be broken down into sorted waste (recycling bins) and unsorted waste (rest bins). Materials are recyclable when they can be mechanically or chemically treated to have the same or similar properties as they had before being used. Recycled materials can be used again for manufacturing new items. An item is reusable when it can be used again without remanufacturing, usually after being cleaned. Recyclable materials can end up in the wrong recycling bin or the residual bin (cross-contamination). Some recyclable items can be recovered from cross-contamination, but some are inevitably lost to landfills and incineration.

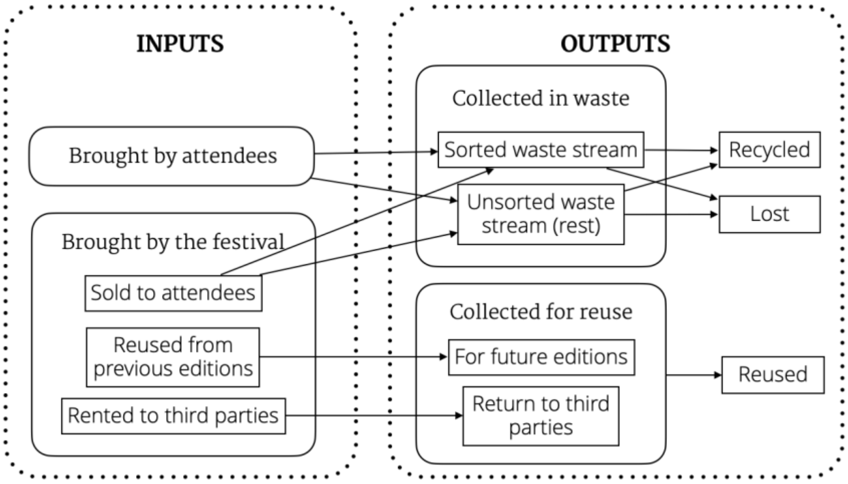

Figure 9: Visual representation of the material flows in music festivals
Source: Own elaboration.

Table 1 shows the parameters used to develop the MFA (including the concepts in Figure 9), their definition, and how we obtained them.

Name in figure	*Name in equations*	*Definition*	*Obtaining*
Brought by attendees	IN_{attd}^{i}	Material i brought by attendees (kg)	Equation 6
Sold to attendees	IN_{sold}^{i}	Material i brought by the festival and sold to attendees (kg)	Bioritme's data
Reused and rented	IN_{reuse}^{i}	Material i brought by the festival that will (or can) be reused (kg)	Bioritme's data
Collected in waste	OUT_{waste}^{i}	Material i collected in the waste stream (correctly and incorrectly sorted) (kg)	Equation 4
(Un)sorted waste stream	OUT_{bin}^{i}	Waste collected in the bin for material i (kg). E.g. OUT_{bin}^{rest} is the amount of waste in the rest bin	Bioritme's data
-	OUT_{sort}^{i}	Amount of material i correctly sorted (kg).	Equation 2
-	OUT_{recov}^{i}	Amount of material i recovered from cross-contamination (kg).	Equation 3
Material recycled	OUT_{recy}^{i}	Material i that will get recycled (kg)	Equation 1
Material lost	OUT_{lost}^{i}	Material i lost in other waste streams (hence, not recycled) (kg)	Equation 5
Collected for reuse	OUT_{reuse}^{i}	Material i that will (or can) be reused (kg). It is equal to IN_{reuse}^{i}.	Bioritme's data

Table 1: Concepts used for the MFA and their definitions
Source: Own elaboration.

Not all the data required for the MFA could be measured in the 2019 edition of Bioritme. Hence, several assumptions and estimations were made:

Cross-contamination of waste streams

Bioritme had bins backstage (only accessible by staff) and bins on-site. For simplicity, we assumed that the backstage bins were used correctly but that the bins on-site had some level of cross-contamination. However, no cross-contamination control was performed in Bioritme 2019. That means that, for instance, if a plastic bin on-site was filled with a material other than plastic, the whole weight of the bin was still considered plastic waste. To estimate the cross-contamination on-site, we used the cross-contamination rates of the municipal waste system in Osona and Catalonia in 2019. Table 2 shows the values for paper, plastic, metals, glass, wood, and organic waste. The amount of material that got recycled (OUT^{i}_{recy}) was calculated by adding up the correctly sorted material and the material recovered from cross-contamination in the bins of lightweight packaging and rest, as follows:

$$OUT^{i}_{recy}(kg) = OUT^{i}_{sort} + OUT^{i}_{recov} \tag{1}$$

$$OUT^{i}_{sort}(kg) = OUT^{i}_{bin} \cdot part^{i}_{i} \tag{2}$$

$$OUT^{i}_{recov}(kg) = OUT^{light}_{bin} \cdot part^{i}_{light} + OUT^{rest}_{bin} \cdot part^{i}_{rest} \tag{3}$$

The portions of non-contaminated paper and glass ($part^{paper}_{paper}, part^{glass}_{glass}$) were calculated as the ratio of net material weight over the gross collected weight of paper and glass in recycling bins in Osona, measured by the Agència de Residus de Catalunya[2] (ARC, 2019). The portions of not contaminated plastic and aluminum ($part^{plastic}_{plastic}, part^{alu}_{alu}$) were calculated as the portion of each material sorted out of the lightweight packaging waste stream in Catalonia 2019 (ARC, 2020b). The ratio of recovered materials incorrectly disposed of in the lightweight packaging waste ($part^{i}_{light}$) and rest bins ($part^{i}_{rest}$) in the festival was considered equivalent to the recovery rates in Catalonia 2019 (ARC, 2020b).

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Wood*	*Rest*
Not contaminated	94%[a]	45%[b]	9%[b]	98%[a]	89%	100%[c]	n/a
Recovered from lightweight packaging	4%[b]	n/a	n/a	0,03%[b]	0%	0%	42%
Recovered from MBT	2%[b]	5%[b]	2%[b]	n/a[d]	19%	0%	72%

Table 2: Percentage of materials collected and recovered from waste streams in Osona and Catalonia 2019.
[a] proportion of net paper and glass collected in Osona 2019, from ARC (2019); [b] portion of material sorted from lightweight packaging waste stream and MBT in Catalonia, from ARC (2020b); [c] wood is disposed of in 'Green Points' and is rarely contaminated; [d] glass was not allowed on-site and was hence not subject to cross-contamination

Lost materials

[2] In English: Catalan Agency of Waste

Lost materials are recyclable materials that, instead of being recycled, end up in landfills or incineration (and therefore, the material is lost). This happens when incorrectly disposed materials cannot be recovered from cross-contamination. We refer to them as primary losses. Secondary losses are the material losses that happen during the recycling process. To estimate how much material was lost, we made a couple of assumptions:

- All paper, plastic, and aluminum products sold (IN_{sold}) were assumed to leave the festival's boundaries in the waste stream, and none was taken home. The only exception was the reusable and non-returnable hard plastic cups, which are generally kept as a souvenir.
- The proportion of each material in the waste collected on-site was assumed equivalent to the proportion of material sold by Bioritme (equation 4). This presumes that Bioritme's attendees behave similarly to the festival in terms of the type of products they bring in. Therefore if, for instance, 20% of the total products sold by the festival were paper products, we assumed that 20% of all the waste collected on-site was also paper. The amount of lost material (OUT_{lost}^{i}) was then calculated by subtracting the amount of material that got recycled from the total amount of material collected (equation 5).

$$\frac{IN_{sold}^{i}}{IN_{sold}} = \frac{OUT_{waste}^{i}}{OUT_{waste}} \quad (4)$$

$$OUT_{lost}^{i} = OUT_{waste}^{i} - OUT_{recy}^{i} \quad (5)$$

Materials brought by attendees

To estimate the amounts of paper, plastic, aluminum, and organic materials brought by the attendees, we subtracted the materials introduced by the festival from the total collected waste:

$$IN_{attd}^{i} = OUT_{waste}^{i} - IN_{sold}^{i} \quad (6)$$

4.3 Phase 2: Environmental impact of Bioritme's WMS

In the second phase, we evaluated the environmental impacts of the waste in Bioritme in terms of avoidance of virgin resource extraction, GHG emissions, and water consumption with the Zero Waste Index, Carbon Footprint, and Water Footprint, respectively. Instead of focusing solely on the impacts of the WMS itself, we expanded the boundaries of the analysis to include other phases of the life of products as described in Figure 4 in Section 0. The life phases under study included raw material extraction, manufacturing, use, and end-of-life (EOL).

4.3.1 Virgin resource consumption

The evaluation of the virgin resource consumption of Bioritme was done with the Zero Waste Index (ZWI). The ZWI assumes that the recovered materials from waste by means of a WMS avoid the extraction of virgin materials (Zaman & Swapan, 2016). The index is measured by multiplying the amount of waste collected from one stream by the substitution factor (SF) of the waste management subsystem that deals with it (referred to as 'subsystem' in this section), as shown in equation 7. The SF describes how much material comes out of a subsystem after the waste stream is treated. It ranges from 0 (no useable material comes out) to 1 (all material can be used after being treated). The index is calculated by adding up all the waste streams dealt by all subsystems and dividing that by the total:

$$ZWI = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} OUT_j^i \cdot SF_j^i}{\sum_{i=1}^{n} OUT_{total}^i} \quad (7)$$

Where:

$i \in [1, \dots, \mathrm{n}]$: material (e.g., paper, plastic...).
$j \in [1, \dots, \mathrm{m}]$: subsystems (reuse, recycling, landfill, incineration).
OUT_j^i : amount of waste stream i managed by subsystem j.
$OUT_{landf\ \&\ incin}^i$ = OUT_{lost}^i from equation 5.
$SF_j^i \in [0, 1]$: substitution factor for the waste stream i when managed by subsystem j (Table 3).
$OUT_{total}^i = OUT_{waste}^i + OUT_{reuse}^i$: total amount of material i collected in waste (equation 4) and for reuse.

The data from the MFA was used for the calculation of the ZWI. For the SF of recycling (SF_{recy}^i) in Table 3, we assumed that all waste was treated in Catalonia.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Wood*
Reuse	100%					
Recycling	95%[a]	65%[a]	98%[a]	98%[a]	100%[c]	99%[b]
Lost	0%					

Table 3: Substitution factors (SF) for each material and subsystem
[a] efficiency of recycling plants in Catalonia 2019 (Inèdit & ARC, 2021); [b] Carrano and Thorn (2014); [c] biomass transformation into water, CO_2, and CH_4 during decomposition are not considered as losses.

4.3.2 GHG emissions

The GHG emissions of the WMS of Bioritme were assessed with a Carbon Footprint (CF). This indicator measures the quantity of GHG released into the atmosphere in terms of kg of CO_2 equivalent (kgCO_2eq). The scope of the CF included the direct and indirect emissions from production (material extraction, product manufacturing) and end-of-life (EOL) (lost, recycled, and reused products). Due to a lack of data about the products brought by attendees, we estimated their emission factor (EF) by averaging the EF of products sold by the festival made from the same material (i):

$$EF_{attd}^i = \frac{\sum EF_{fest}^i}{num\ products_{fest}^i} \quad (8)$$

Table 4 shows the EF of each EOL method for each material, and Appendix B shows the EF of raw material extraction and manufacture of the products sold by the festival.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Wood*	*Other*
Recycling ($kgCO_2eq/kg$)	0,04	0,03	0,02	0,001	0,28[a]	0,02	n/a
Landfill ($kgCO_2eq/kg$)	2,00	0,003	0,003	0,003	0,83	n/a	0,77
Incineration ($kgCO_2eq/kg$)	-0,09	2,44	0,04	0,04	Unknown[b]	n/a	0,30

Table 4: End-of-life emission factors for each material.
Source: Inèdit and Agència de Residus de Catalunya (2021).
[a] *Calculated by weight averaging the emissions of composting and anaerobic digestion. The values were extracted from Inèdit and ARC (2021);* [b] *The emissions of organic waste ending up in the residual waste stream were calculated using only the EF of landfills.*

To calculate the CF, we added up the emissions of production (equation 9), lost products (equation 10), recycled products (equation 11), and reused products (equation 12). Emissions from transportation to and from the festival were not considered.

- The emissions of producing the products (P) were calculated using the emission factor of raw material extraction (EF^P_{raw}) and product manufacturing (EF^P_{manuf}). If the product was reused, the emission factors were divided by the product's expected lifespan ($uses$), measured in festival editions. For the particular case of the reusable (but non-returnable) hard plastic cups, the product life was just 1 edition because new cups are sold in each edition:

$$CF^P_{prod} = IN^P_{sold} \cdot \left(EF^P_{raw} + EF^P_{manuf}\right) + IN^P_{reuse} \cdot \frac{EF^P_{raw} + EF^P_{manuf}}{uses} \tag{9}$$

- The emissions of lost materials (CF^i_{lost}) were calculated using the percentage of rest that ends up in landfill ($\%_{landf}$) and incineration ($\%_{incin}$) and their respective emission factors:

$$CF^i_{lost}\ (kgCO_2eq) = OUT^i_{lost} \cdot \%_{landf} \cdot EF^i_{landf} + OUT^i_{lost} \cdot \%_{incin} \cdot EF^i_{incin} \tag{10}$$

- The emissions of recycling materials (CF^i_{recy}) refer to the emission of the recycling process itself minus the emissions of the raw material extraction that is avoided:

$$CF^i_{recy}\ (kgCO_2eq) = OUT^i_{recy} \cdot EF^i_{recy} - OUT^i_{recy} \cdot SF^i_{recy} \cdot EF^i_{raw} \tag{11}$$

- The emissions of reused products (CF^i_{reuse}) correspond to the emissions of repurposing the product for future uses.

$$CF^i_{reuse}\ (kgCO_2eq) = IN^i_{reuse} \cdot EF^i_{reuse} \tag{12}$$

4.3.3 Water Footprint

The scarce availability of water in Spain (Garrote, Iglesias, & Granados, 2018) makes it especially important to evaluate the water consumption levels of Bioritme. The assessment was done with the Water Footprint (WF), an indicator of freshwater resource appropriation. We focused on the blue and gray WF. The blue WF measures the volume of run-off water that does not return to its catchment due to human activities. It is calculated by adding up the amount of water lost through evaporation, water incorporated into products, and water returned to another catchment, discharged at sea, or returned at another time. The gray WF measures the amount of water required to safely assimilate waste. It is measured by quantifying the amount of water needed to dilute pollutants to such an extent that the quality of ambient water is above agreed water quality standards (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011).

The scope of the WF of the WMS of Bioritme includes, on the one hand, the direct water used on-site and on the other hand, the indirect water used for extracting raw materials and manufacturing products (W_{prod}) and treating them at the EOL (W_{lost}, W_{recy}, and W_{reuse}). The direct water used on-site was only the bottled drinking water and the ice sold. Water for showers and sinks was not potable and was extracted and returned to the Sau reservoir (after filtering it). Thus, it does not count as appropriated water under the definition of Hoekstra et al. (2011). The water footprints of production and EOL were calculated in the same way as the carbon footprints (quations 8-11), using the water use factors in Appendix C.

4.4 Phase 3: Zero-waste measures in Bioritme's WMS

The measures taken to get closer to the zero-waste goal must be carefully selected, so they do not backfire and increase other environmental impacts. In this phase, we simulated three scenarios with different zero-waste measures that could increase Bioritme's ZWI, summarized in Table 5. The MFA, ZWI, CF, and WF of the three scenarios were compared with the business-as-usual scenario. The choice of zero-waste measures was based on the elements that maximize the ZWI equation (7): materials with high substitution factor[3] (recycling scenario), better sorting (sorting scenario), and reuse (reuse scenario).

Scenario	*Description*
Business-as-usual scenario (BAU)	Reference scenario calculated with values from Bioritme 2019

[3] The substitution factor (SF) is a value that ranges from 0 to 1 and describes how much useable material comes out of a waste management system. For example, landfill has SF = 0 and reuse has SF = 1. The SF of recycling depends on technical limitations of the material being recycled and the infrastructure in place.

Recycling scenario (RECY)	Scenario where the festival fosters the use of materials with high SF
Sorting scenario (SORT)	Scenario where the festival focuses on ensuring good collection and sorting to reduce cross-contaminated waste streams
Reuse scenario (REU)	Scenario where the festival incentivizes reusable over single-use products whenever possible

Table 5: Scenarios with different zero-waste measures.

4.4.1 Recycling scenario

In this scenario, the festival focuses only on minimizing the use of materials with low substitution factors (SF). Table 3 in Section 4.3.1 shows the SF of paper, plastic, aluminum, glass, organic, and wood in Catalonia. The material with the lowest SF is plastic (SF = 0,65), and in this scenario, it is substituted with organic materials (SF = 1), aluminum, or glass (SF = 0,98) whenever possible. This scenario targets the minimization of plastic brought both by the festival and by the audience. To address the audience's plastic waste, the festival offers plastic-free groceries on-site. Since there is a no-glass policy in Bioritme, no glass containers are sold in the plastic-free store.

Behavioral changes towards sustainable consumption depend on individual patterns rather than social pressure (Cecere, Mancinelli, & Mazzanti, 2014). Hence, personal beliefs and the audience's consumption behavior will determine the success of the plastic-free grocery store. Bioritme's audience is generally environmentally aware but also very young and money conscious. We made an educated guess that, in the first year of implementation, the plastic-free store would be used by 5% of the people in the age group older than 25. That corresponds to 3% of the total attendees, or 120 people (4800 attendees x 50% older than 25 x 5% behavioral change). A best-case scenario of 100% of the target group was also evaluated (4800 attendees x 50% older than 25 = 2400 people) to check the potential of the plastic-free store.

Although Bioritme allows attendees to cook at the camping grounds, people tend to opt for easy meals with the smallest effort in a music festival (Binns, 2019). The plastic-free grocery store would sell food often brought to festivals such as instant noodles, bread, spreads (e.g., hummus), snacks (e.g., nuts, cereals), and fruit and vegetables. Non-alcoholic drinks would also be sold plastic-free. Table 6 shows the substituted materials backstage and on-site. The numbers in the table correspond to what a group of four people would purchase in the plastic-free store (instead of a conventional supermarket) over four festival days. The proportions are based on the personal experience of the authors.

Level	*Substituted*	*Alternative*
BACKSTAGE	5L wine boxes (cardboard + plastic liner)	0,75L glass wine bottles
	1L juice and milk cartons	1L juice and milk glass bottles
	1,5L PET water bottles	1L glass water bottles
	PP straws	PLA straws

	PP hard cups (reusable but non-returnable)	Aluminum hard cups (reusable but non-returnable)
AUDIENCE	Plastic food and drinks packaging from home (4 people 4 nights):	Plastic-free grocery store with:
	- 8 plastic packs of instant noodles	- 1 paper bag of instant noodles in bulk
	- 2 plastic bags of bread	- 2 paper bags of bread in bulk
	- 4 hard plastic packs of spreads (hummus, jam)	- 4 tins of spreads
	- 2 cardboard boxes + 2 plastic liners for cereals	- 2 compostable plastic bags (bulk)
	- 2 flexible plastic packs of dry snacks (e.g., nuts)	- 2 compostable plastic bags (bulk)
	- 4 plastic produce bags for fruit and vegetables	- 4 compostable plastic bags (bulk)
	- 6 plastic bottles of soft drinks of 1l	- 18 aluminum cans of 330ml
	- 2 cartons of plant-based milk of 1l	- 2 compostable plastic bottles of plant-based milk of 1l
	- 2 cartons of juice of 1l	- 2 compostable plastic bottles of juice of 1l

Table 6: Measures taken in the Recycling scenario and their effect on the MFA of Bioritme.

The input and output streams were recalculated with the new materials. From the original input of attendees ($IN_{attd_{old}}$), the substituted products (P_{subs}) were subtracted (equation 13). The alternatives introduced by the festival backstage and in the plastic-free store (P_{alter}) are added up to the input stream of the festival ($IN^i_{fest_{old}}$) (equation 14). The new total material ($OUT^i_{total_{new}}$) is calculated by adding up the new inputs of the festival and the attendees (equation 15). The proportion of recycled material versus lost material is kept the same as in the original MFA because no cross-contamination measures are taken in this scenario (equation 16). The CF and WF were calculated in the same way as in BAU but replacing the CF and WF of the substituted materials with their alternatives.

$$IN^i_{attd_{new}} = IN^i_{attd_{old}} - P^i_{subs} \tag{13}$$

$$IN^i_{fest_{new}} = IN^i_{fest_{old}} - P^i_{subs} + P^i_{alter} \tag{14}$$

$$OUT^i_{total_{new}} = IN^i_{fest_{new}} + IN^i_{attd_{new}} \tag{15}$$

$$OUT^i_{recy_{new}} = OUT^i_{total_{new}} \cdot \frac{OUT^i_{recy_{old}}}{OUT_{total_{old}}} \tag{16}$$

4.4.2 Sorting scenario

In this scenario, the festival does not change the purchases and sales but instead focuses on minimizing cross-contamination by ensuring good collection and sorting. To do that, recycling bins are strategically placed with explicit signaling and volunteers helping people to sort their waste. Zelenika et al. (2018) found that volunteer-staffed bins in festivals reduced cross-contamination by 96% in organic bins, 97% in lightweight packaging bins, and 97% in paper bins. Since this measure requires an extensive volunteer force, we simulated different ratios of staffed bins: 10%, 30%, and 50%. Table 7 shows how each ratio affects the overall collection rates.

	Reduction per staffed bin	*Total cross-contamination reduction*		
		10% staffed bins	30% staffed bins	50% staffed bins
Paper bins	97%	9,7%	29,1%	48,5%
Lightweight bins	97%	9,7%	29,1%	48,5%
Organic bins	96%	9,6%	28,8%	48%

Table 7: Cross-contamination reduction percentages of paper, lightweight, and organic bins in different ratios of staffed bins.

The materials flowing in this scenario remain the same, but the end-of-life of each stream will vary with the reduced cross-contamination values. Keeping the collected material constant (OUT^{i}_{total}), we calculated how much of it would be correctly sorted (OUT^{i}_{sort}), and how much would be cross-contamination (OUT_{cont}):

$$OUT^{i}_{total_{new}} = OUT^{i}_{total_{old}} = OUT^{i}_{sort} + OUT^{i}_{cont} \tag{17}$$

Part of the incorrectly sorted material is recovered from other waste streams (OUT^{i}_{recov}), and the rest is lost to landfill or incineration (OUT^{i}_{lost}):

$$OUT^{i}_{cont} = OUT^{i}_{recov} + OUT^{i}_{lost} \tag{18}$$

The total recycled material is, hence, the sum of correctly sorted and the recovered material:

$$OUT^{i}_{recy} = OUT^{i}_{sort} + OUT^{i}_{recov} \tag{19}$$

The incorrectly sorted materials in SORT are calculated by subtracting the reduced percentage of cross-contamination from Table 7 ($\%_{reduc}$) from incorrectly sorted materials in BAU:

$$OUT_{cont_{SOR}} = OUT_{cont_{BAU}} - OUT_{cont_{BAU}} \cdot \%_{reduc} \tag{20}$$

The percentage of primary losses and recovered materials is maintained:

$$OUT_{lost_{SOR}} = OUT_{cont_{SOR}} \cdot \frac{OUT_{lost_{BAU}}}{OUT_{cont_{BAU}}} \tag{21}$$

$$OUT_{recov_{SOR}} = OUT_{cont_{SOR}} \cdot \frac{OUT_{recov_{BAU}}}{OUT_{cont_{BAU}}} \tag{22}$$

These values represent only the waste on-site because it was assumed that no cross-contamination happened backstage. The total correctly sorted waste was found by adding the waste collected backstage and OUT^{i}_{sort}. Finally, we calculated the residual waste stream by adding up the non-recyclable materials flowing on-site (OUT^{rest}_{total}) and the primary losses from recyclable materials (OUT^{paper}_{lost} , $OUT^{plastic}_{lost}$, OUT^{alu}_{lost}, OUT^{org}_{lost}):

$$OUT_{rest_{SOR}} = OUT_{total}^{rest} + \sum_{i \in materials} OUT_{lost_{SOR}}^{i} \tag{23}$$

The ZWI, CF, and WF of this scenario were calculated in the same way as in BAU but with the new MFA values.

4.4.3 Reuse scenario

In this scenario, the festival focuses on using reusable items rather than disposable ones whenever possible. Reuse measures are summarized in Table 8. At the backstage, the take-home PP hard cups are substituted by returnable cups rented from an external company. Thus, the life of the cups is extended as they can be cleaned and used again in other events. Soft drinks in disposable packaging are substituted with concentrated syrup mixed with carbonated water from a fountain. This reduces the use of disposable plastic bottles and cans, as one bottle of 440ml of syrup makes up to 9l of soft drinks (SodaStream, 2021). To reduce the plastic water bottles sold, the audience is encouraged to bring their own reusable water bottles, which are refillable in the bars using the same water fountains as for the carbonated water. The Dutch festival Into The Great Wide Open switched from bottled water and soda to syrup and carbonated water in 2018 and had very positive results (van de Voort & Schurink, 2018). Single-use sugar packets are phased out and substituted with refillable sugar glass jars. The Portuguese festival Andanças successfully made this switch with a very favorable response from the audience (Martinho et al., 2018). The last backstage measure incentivizes the audience to bring their own coffee cups and tableware with discounts on purchased food and drinks.

Regarding the audience measures, the festival provides a package-free grocery store to buy some basic food in bulk. In the same way as in RECY, the uptake of the package-free store depends on individual consumption patterns (Cecere et al., 2014). The same two uptake levels were used for the package-free store as in RECY: 5% of the audience over 25 years old (120 people) and 100% of the audience over 25 (2400 people).

Level	*Original*	*Substitution*
BACKSTAGE	Non-returnable PP cups	Returnable PP cups
	330ml cans of soft drinks	440ml concentrated syrup HDPE bottles + carbonated water from a fountain
	1,5L PET water bottles	Water fountains
	Single-use sugar packet	Refillable glass jars
	Single-use coffee cups and cutlery	BYO reusable coffee cups and cutlery
AUDIENCE	Food and drinks packaging from home including:	Awareness campaign and package-free grocery store with:
	- 8 plastic packs of instant noodles	- Instant noodles in bulk
	- 2 plastic bags of bread	- Bread in bulk
	- 2 cardboard boxes + 2 plastic liners for cereals	- Cereals in bulk
	- 2 flexible plastic packs of dry snacks (e.g., nuts)	- Dry snacks in bulk
	- 4 plastic produce bags for fruit and vegetables	- Fruit and vegetables in bulk

Table 8: Measures taken under the reuse scenario and their effect on the MFA of Bioritme.

To recalculate the inputs of this scenario, we had to make some assumptions. First, we considered that all cups were returned at the end of the event without losses. Since the cups are rented to an external company and used in other events, the number of uses of the reusable cup increased from 1 to 100 uses (Event Cup Solutions, 2020). Second, we assumed that 4 glass jars (2 in each coffee-selling bar) were used to substitute all sugar packets and that they were reused in future editions. Third, we considered that the same number of people purchased in the package-free store brought their own reusable bottles, coffee cups, and cutlery ($people_{BYO}$). The new number of disposable bottles, cups, and cutlery was calculated by subtracting the number of bottles, cups, and cutlery that each of the $people_{BYO}$ would have consumed from the total:

$$OUT_{bottle_{REU}} = OUT_{bottle_{BAU}} - people_{BYO} \cdot \frac{OUT_{bottle_{old}}}{people_{total}} \quad (24)$$

Equations 13 to 16 from RECY were used again in this scenario to calculate how the attendees' input and the collected waste changed due to the package-free store. The only difference is that in the package-free store, no products are sold with packaging, and hence, P^{i}_{alter} is always 0. The CF and WF were calculated in the same way as in BAU but replacing the CF and WF of the substituted materials with the alternatives.

5. Results

This chapter presents the findings of our research. Section 5.1 describes the flows of materials in the case-study festival Bioritme in 2019, with a Material Flow Analysis; Section 5.2 presents the environmental impacts of the materials in terms of virgin resource consumption, GHG emissions, and water use; and finally, Section 5.3 simulates the implementation of three zero-waste measures in Bioritme and evaluates their environmental implications.

5.1 Phase 1: Material Flow Analysis

The material flows of the 2019 edition of Bioritme are broken down in Appendix A and illustrated as a Sankey diagram in Figure 10. The main flows by material and EOL (reuse, recycle, lost) are summarized in Table 9, differentiating between materials brought by the festival and by attendees. The total material that gets recycled covers the amount collected in the correct sorting bins and the amount recovered from cross-contamination. Glass and wood were disposed of only in backstage bins without cross-contamination. The organic stream includes compostable packaging and food waste. However, the origin of the waste could not be estimated due to a lack of data about food sold on-site. The recyclable materials that were not recovered from cross-contamination ended up incinerated or in landfills ('lost').

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Wood*	*Other*
Total in (kg)	**11.377**	**4.904**	**1.166**	**176**	**2.512**	**5.850**	**26.834**
From festival	685	292	89	176	unknown	5.850	26.753
From attendees	10.693	4.612	1.076	0	unknown	0	82
Total out (kg)	**11.377**	**4.904**	**1.166**	**176**	**2.512**	**5.850**	**26.834**
Reused	0	180	0	0	0	5.400	26.749
Recycled	10.484	4.578	1.049	176	2.310	450	0
Correctly disposed	10.040	4.484	1.005	176	1.930	450	0
Recovered from cross-contamination	445	95	45	0	380	0	0
Lost	893	146	117	0	202	0	85

Table 9: Summary of input and output flows, including infrastructure.

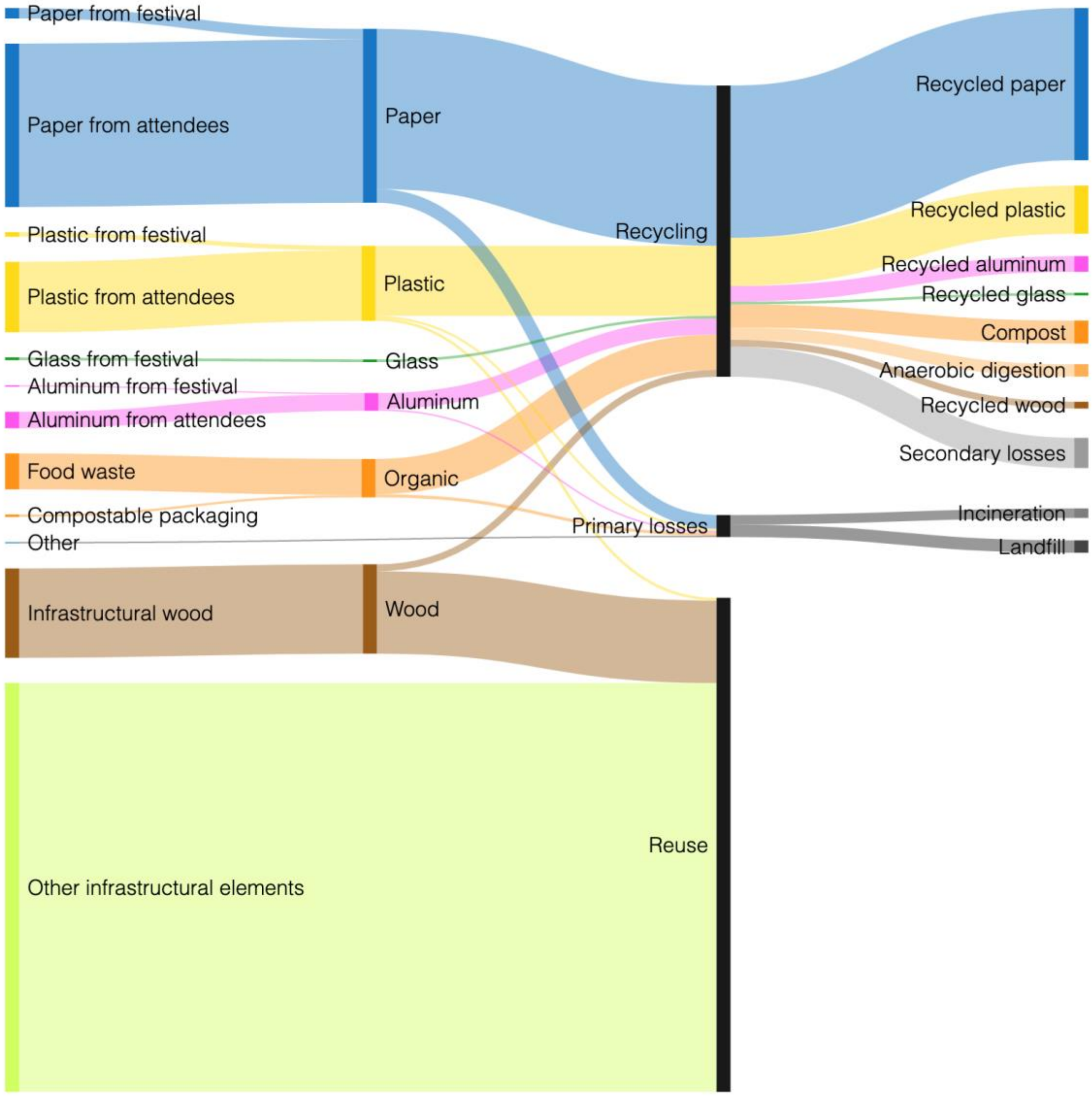

Figure 10: Material Flow Analysis of Bioritme 2019.

The MFA shows that, for the most part, Bioritme adhered to the waste management hierarchy and either reused (61%) or recycled (36%) the materials that circulated in the festival. Only a tiny fraction (3%) was lost to landfills or incineration. In Section 5.2, we will provide more insights into the environmental implications of such waste distribution. The reused materials were infrastructural elements that Bioritme either rented from third parties (stages) or reused from previous editions (fences, signaling, decoration, and wood pallets). From all the wasted materials (recycled or lost), over 90% were brought in by the attendees, and only a small part was under the direct responsibility of the festival. Nonetheless, the amount of waste per person per day in Bioritme 2019 was 0,9kg/person/day, way below the average waste left in festival camping grounds in other countries such as the Netherlands (2,33kg/person/day) (van de Voort & Schurink, 2018) or the UK (2,8kg/person/day) (Johnson, 2015). This can be related to very low levels of camping gear waste in Bioritme –as opposed to the average Dutch and British festivals (AIF, 2019).

The distribution of non-infrastructural materials flowing in Bioritme was 56% paper, 24% plastic, 12% organic, 6% aluminum, 1% glass, and 0,42% residual, depicted in Figure 11 (right pie chart). This distribution is very similar to the material distribution of the recyclable waste in Catalonia in 2019, where paper was the most collected material, followed by organic, glass, plastic, and aluminum (ARC, 2020a). The small amount of residual waste in Bioritme results from assuming that the proportion of each material in the waste collected on-site was equivalent to the proportion of material sold by Bioritme (more details on this assumption in Section 4.2). Considering that most of the waste collected likely came from food and drinks packaging brought by attendees, it can seem odd that plastic does not constitute a higher share in the weight of collected material. Nonetheless, these measures are based on weight and not on the number of items collected. Paper is heavier than plastic: one paper bag is almost ten times as heavy as a plastic one (ABC News, 2006).

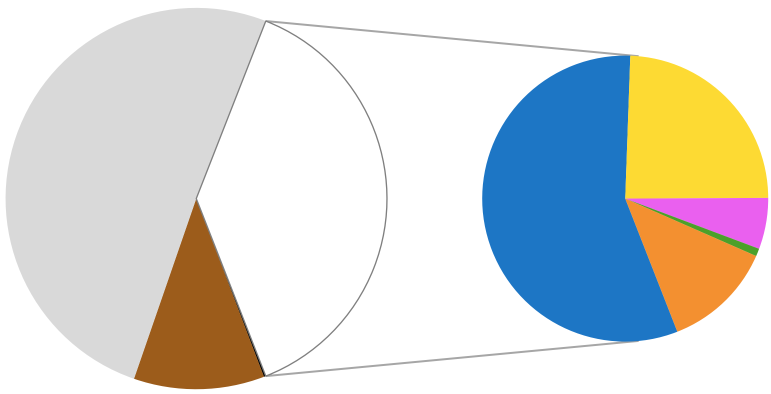

Figure 11: Composition of the materials flowing in Bioritme 2019.

Despite having sorting bins distributed across the site for paper, lightweight packaging (plastic and aluminum), organic, and rest, some materials were inevitably misplaced. As explained in Section 4.2, we assumed that cross-contamination only happened on-site and not in the backstage bins. Sometimes materials can be recovered from cross-contamination, but if they are not, they end up landfilled or incinerated (secondary losses). Figure 12 shows how much of each material was correctly disposed backstage and on-site, recovered from cross-contamination, lost, and reused. Glass and wood are excluded from the plot because they were exclusively handled backstage. In 2019, 88% of all recyclable materials in Bioritme were correctly sorted. Out of the 12% cross-contaminated waste, 42% was recovered, and the rest was lost. From the waste collected on-site, plastic had the highest collection rate (95%) and only 3% primary losses. Organic waste and aluminum had the lowest collection rates, 85% and 75%, respectively. Nevertheless, since residual waste in Osona is treated in mechanical-biological treatment plants, 65% of the misplaced organic waste was recovered.

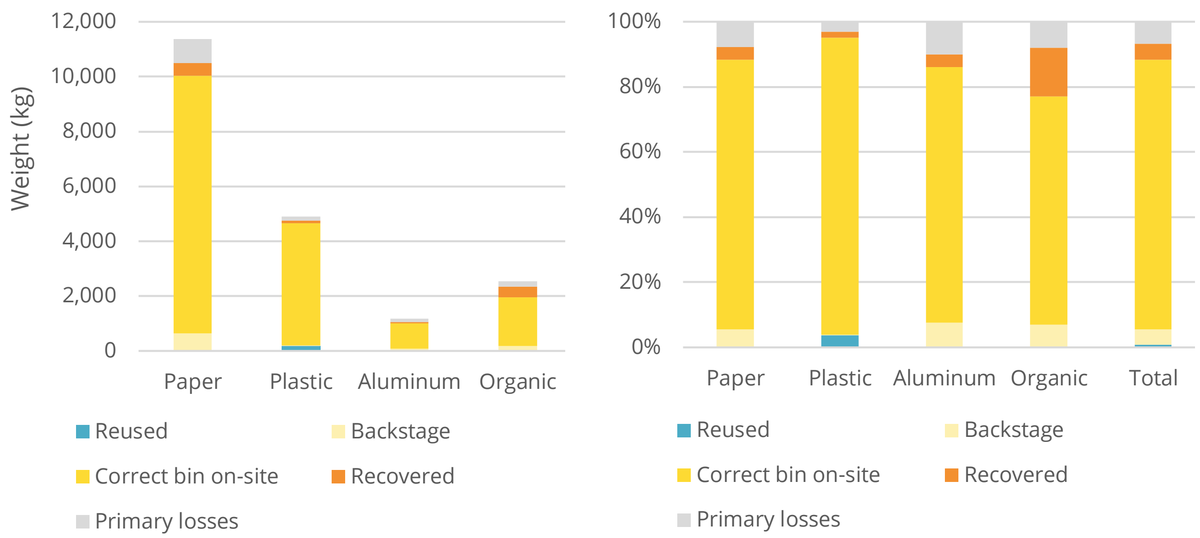

Figure 12: Absolute (left) and normalized values (right) of each material stream's collection, recovery, and primary losses.

5.2 Phase 2: Environmental impact of Bioritme's WMS

5.2.1 Zero-Waste Index

The Zero Waste Index (ZWI) of Bioritme 2019 was 0,93. This means that 93% of materials were recovered from the waste stream, indicating that Bioritme is somewhat close to being zero-waste. The high ZWI is significantly influenced by the fact that infrastructure –the heaviest material stream– is mainly reused. Table 10 shows the ZWI of each material stream and the total including and excluding infrastructure. When the ZWI is calculated without infrastructure, it drops to 0,83.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Wood*	*Other*	***Total***
SF_{recy}	0,95	0,65	0,98	0,98	1	0,99	0	n/a
ZWI	**0,88**	**0,64**	**0,88**	**0,98**	**0,92**	**1,00**	**1,00**	**0,93 (0,82)[a]**
From festival	0,94	0,86	0,98	0,98	1	1	1	0,997 (0,94)[a]
From attendees	0,87	0,63	0,87	n/a	0,91	n/a	0	0,81

Table 10: Substitution factor of recycling (SF) and Zero Waste Index (ZWI) of the materials in Bioritme 2019.
[a] without infrastructure.

The ZWI depends on collection levels (Figure 12 above) and substitution factors (SF) (Table 3). The SF is bound to technical limitations of the recycling process. Not all the correctly sorted material will actually be recycled, and secondary material losses can occur. Figure 13 shows the amount of recycled and lost materials in Bioritme. Organic waste treated in industrial composters and anaerobic digesters become biomass, water, CO_2, and CH_4, without secondary losses. Despite having high collection rates, these values reveal that a significant amount of plastic did not get recycled because of its low SF. On the other hand, paper and aluminum have high SF, and hence their ZWI is bound to cross-contamination levels.

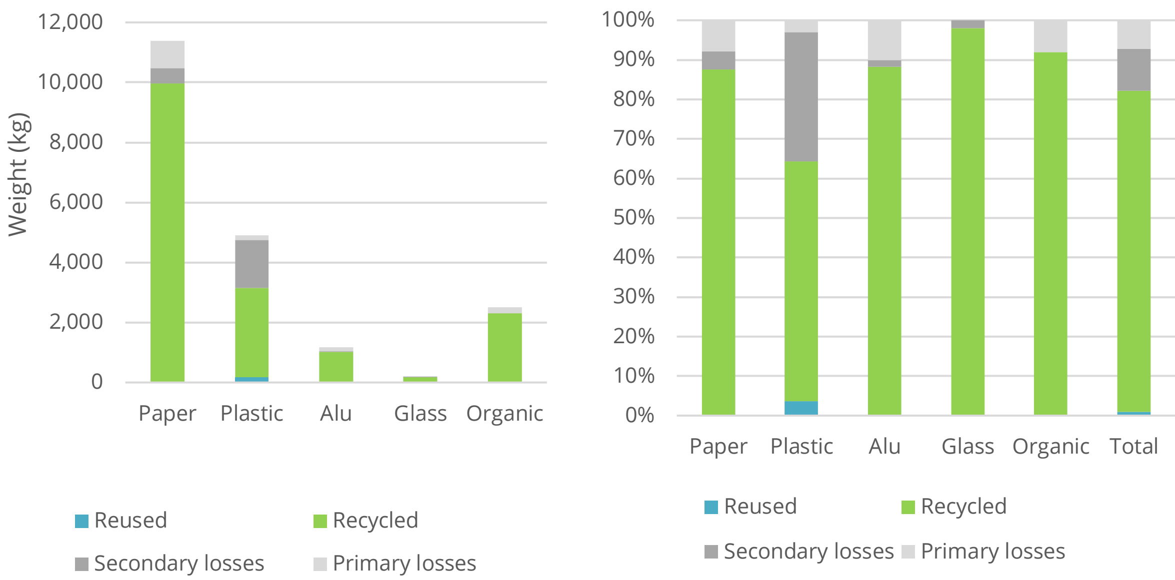

Figure 13: Absolute (left) and normalized values (right) of the reuse and recycling levels, primary losses, and secondary losses of each material stream.

5.2.2 Carbon Footprint

The Carbon Footprint (CF) of the materials flowing in Bioritme are summarized in Table 11, differentiating between the emissions of production, recycling, reuse, and landfilling or incinerating ('losing') the materials. Production includes emissions of raw material extraction and manufacturing. The emissions of recycling include the emissions of the recycling process minus the emissions of the raw material extraction that is avoided (equation 11 in Section 4.3.2). The CF of producing organic materials could not be calculated due to a lack of data about the food sold on-site. To our best knowledge, no data was available for the emissions of assembling and dismantling reusable infrastructure. The emissions of cleaning the hard plastic cups for reuse are zero because they were cleaned by hand.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Wood*	*Other*
CF production ($kgCO_2eq$)	**40.187**	**33.010**	**16.260**	**194**	**Unknown**	**56**	**Unknown**
From festival	2.260	1.067	1.248	194	Unknown	**Unknown**	Unknown
From attendees	37.927	31.943	15.013	0	Unknown	0	Unknown
CF recycling ($kgCO_2eq$)	**-9.616[a]**	**-3.898[a]**	**-12.429[a]**	**-100[a]**	**655[b]**	**6[a]**	**n/a**
From festival	-625	-93	-1.060	-100	44	6	n/a

From attendees	-8.991	-3.805	-11.369	0	611	0	n/a
CF reuse ($kgCO_2eq$)	**n/a**	**0**	**n/a**	**n/a**	**n/a**	**Unknown**	**n/a**
CF losing ($kgCO_2eq$)	**972**	**156**	**2**	**0**	**167**	**0**	**48**
From festival	4	3	0	0	0	0	2
From attendees	968	152	2	0	167	0	46
CF total ($kgCO_2eq$)	**31.544**	**29.268**	**3.834**	**93**	**822**	**62**	**48**
From festival	1.640	977	188	93	44	62	2
From attendees	29.904	28.290	3.646	0	778	0	46

Table 11 Carbon Footprint of the materials flowing in Bioritme 2019.
[a] emissions of the recycling process and avoided emissions from the recycled materials; [b] emissions from composting and anaerobic digestion only.

The total CF of the materials flowing in Bioritme was 66 tons of CO_2eq, and the contribution of each material is shown in Figure 14. The material that contributed the most to the CF was paper, responsible for almost half of the total emissions (48%), followed by plastic (45%) and aluminum (6%). The top-three emitters coincide with the most wasted materials in the festival (Figure 11). Even though the MFA showed that wood and infrastructural elements were the most used, they are the ones that contributed less to the CF. That has two reasons: first, there was no available data about the production of "other" materials and, second, they mainly were reused. It is important to note that the total CF of Bioritme would be significantly higher if food waste emissions could have been measured, as food production contributes significantly to climate change (OECD, 2016).

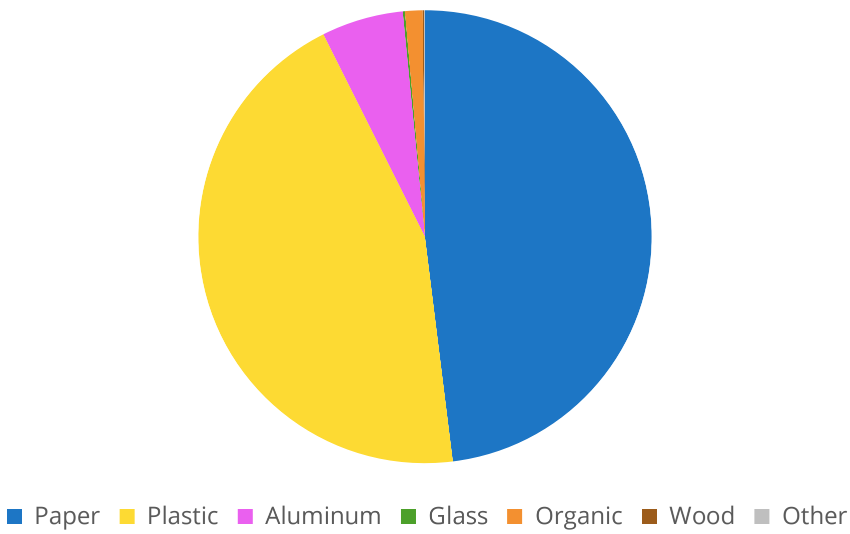

Figure 14: Percentage of the carbon footprint of Bioritme 2019 that corresponded to each material stream.

Normalizing the emissions of each material stream ($kgCO_2eq$ per kg of material used) gives a better idea of how big their CF is, irrespectively to how much of it was used in Bioritme. Figure 15 shows the normalized emissions of each material split into the different life cycle phases. To show the impact of each end-of-life option (recycle vs. losses), the figure excludes the reused materials. Aluminum has very high CO_2 emissions associated with raw material extraction because it was assumed that all the aluminum used was primary aluminum –extracted from ores– which is extremely energy-intensive (Yang et al., 2019). Paper and plastic, on the other hand, are most energy-intensive during the manufacturing phase.

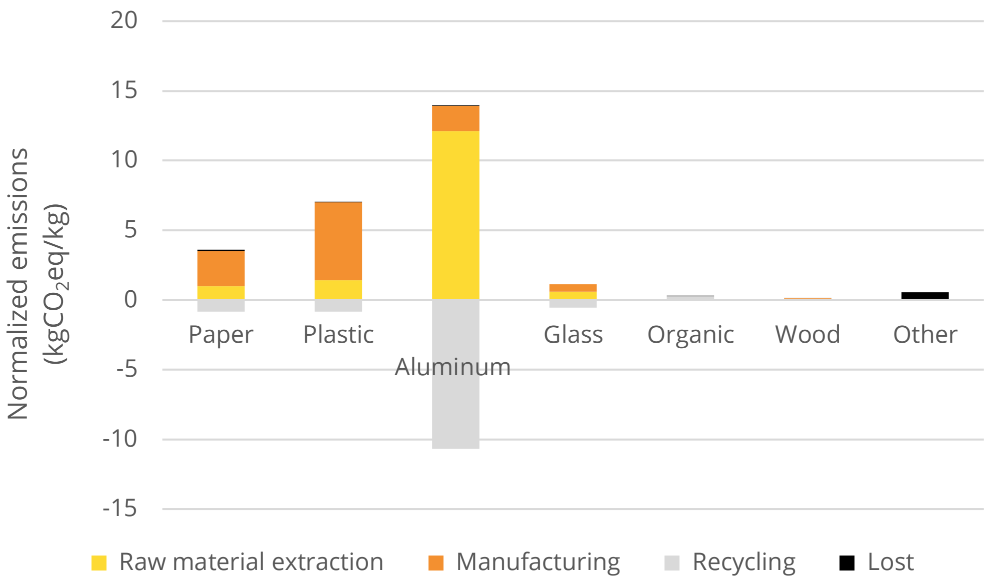

Figure 15: Normalized emissions of each material stream.

5.2.3 Water Footprint

The Water Footprint (WF) of Bioritme was broken down first into direct WF (i.e., water use during the festival) and indirect WF (i.e., water use embedded in the products), and then into blue WF (i.e., consumption of surface and groundwater) and gray WF (i.e., water needed to assimilate the pollution generated). Table 12 and Table 13 summarize the direct and indirect WF of Bioritme, differentiating between blue and gray WF.

- **Direct WF:** water used in showers and sinks was taken and returned to the Sau reservoir after filtering it. This water was not potable; thus, the direct blue WF consisted only of bottled water and ice brought into the festival from other water catchments. The direct gray WF was zero, as the filtering system ensured that the water returning to the reservoir was clean.
- **Indirect WF:** the indirect WF could not be accurately calculated. Water use factors of production and waste treatment were scarce. WF literature typically focuses on the agricultural industry, and data about non-agricultural materials are incomplete. The WF of the products brought by the attendees was not calculated since it involved too many assumptions based on incomplete data, leading to misleading conclusions. There was also a lack of literature on the WF of recycling, landfill, and incineration. Recycling processes generally use closed water systems for cleaning and cooling (Borchardt, 2006). Therefore, the contribution of the water used in

recycling to the total WF would be small. Landfilling and incinerating waste requires no water inputs, and hence their blue WF would be negligible. However, these EOL methods often produce leachate and pollute groundwater (Assi et al., 2020; Wiszniowski et al., 2006), which would likely increase the indirect gray WF. The WF of organic materials includes compostable materials sold by the festival, such as napkins or compostable plastic. The WF of food could not be calculated due to a lack of data. Regarding reuse, no water was needed to reuse infrastructural elements, and the reusable hard cups were washed using the closed water system of the festival and therefore had no WF.

	Showers and sinks	*Drinking water*	*Ice*
WF direct (m^3)	**0**	**5**	**4**
Blue WF	0	5	4
Gray WF	0	0	0

Table 12: Bioritme's direct water footprint.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Wood*
WF production (m^3)	**733**	**10**	**2**	**21**	**131**	**729**
Blue WF	40	10	2	4	17	729
Gray WF	693	0	0	17	114	Unknown
WF recycling (m^3)	**-2**	**1,2**	**-0,5**	**-0,4**	**-0,07**	**-523**
Blue WF	-2	1,2	-0,5	-0,4	-0,07	-523[a]
Gray WF	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
WF reuse (m^3)	**0**	**0**	**0**	**0**	**0**	**0**
WF losing (m^3)	**Unknown**	**Unknown**	**Unknown**	**Unknown**	**Unknown**	**Unknown**
Blue WF	0	0	0	0	0	0
Gray WF	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
WF indirect total (m^3)	**731**	**11**	**2**	**20**	**131**	**206**
Blue WF	38	11	2	4	17	206
Gray WF	693	0	Unknown	17	114	Unknown

Table 13: Bioritme's indirect water footprint.
[a] no data was available for water-use of wood recycling. This value corresponds to the water needed to produce the amount of wood that got recycled.

The contribution of each material to the WF of Bioritme is shown in Figure 16. The material that contributed the most to the WF, by far, was paper (66%), followed by wood (19%) and organic materials (12%). Paper, wood, and organic materials come from agriculture, a sector responsible for 69% of the global water withdrawal (Zhan-Ming & Chen, 2013). Therefore, even if more data would have been available for the non-agricultural materials (plastic, aluminum, and glass), the top three would have likely remained the same. However, it is important to note that the water footprint of the organic stream only includes compostable plastics. Incorporating data about food would probably increase the contribution of this stream to the total WF.

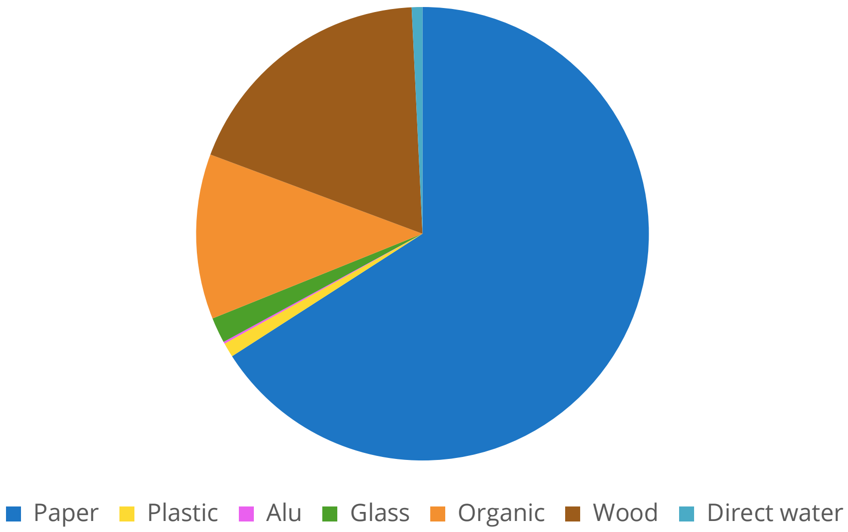

Figure 16: Percentage of the water footprint of Bioritme 2019 that corresponded to each material stream

When the water use is normalized (l of water per kg of material used), the most water-intensive materials become more evident. Figure 17 shows that glass is the most water-intensive material, despite having a small contribution to the total WF and being a non-agricultural material. 83% of the water footprint of glass corresponds to the water needed to assimilate the pollution when creating the material (95 liters of water per kg of glass). Plastic and aluminum have very small WF because they need little water to be made. The figure also shows that raw material extraction is the phase of the life of all products in which more water is required.

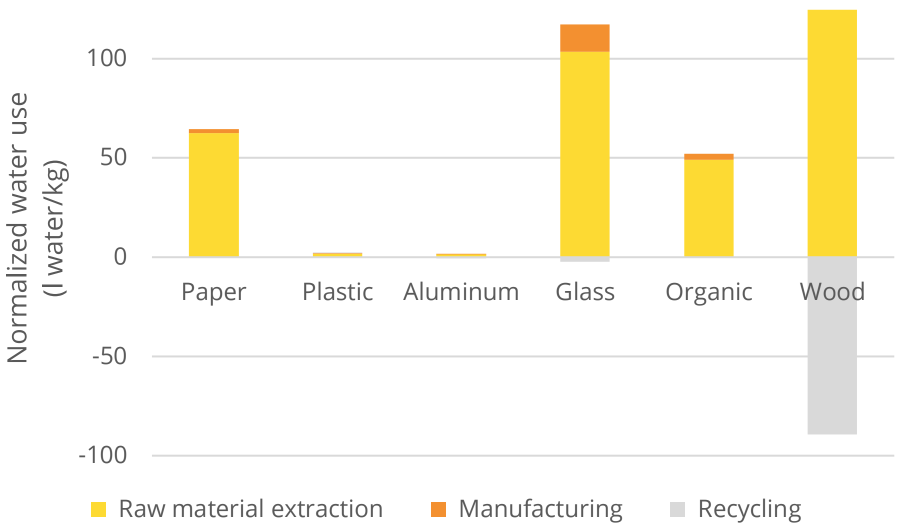

Figure 17: Normalized water use of each material stream per life-cycle phase.

5.3 Phase 3: Zero-waste measures in Bioritme's WMS

In this section, we present how the MFA, ZWI, CF, and WF change based on three simulated scenarios: recycling scenario (RECY), sorting scenario (SORT), and reuse scenario (REU) (first introduced in Section 4.3, Table 5). The results are compared with the business-as-usual scenario (BAU), which corresponds to the 2019 edition of Bioritme.

5.3.1 Recycling scenario

This scenario simulates that the festival substitutes materials with low substitution factor[4] (SF) with alternatives with high SF without changing collection rates. Table 14 shows the flows of non-infrastructural materials under five different variations of RECY, illustrated in Figure 18 (left). The measures of this scenario (explained in Section 4.4.1, Table 6) were combined into five different variations that we named A, B, C, D, and E. In variations A and B, a plastic-free store is implemented with 3% and 50% uptake, respectively. In variation C, the festival substitutes all the plastic products used backstage for other alternatives. Variations D and E combine A+C and B+C, respectively. Figure 18 (left) shows the composition of the materials flowing in RECY, and Figure 18 (right) shows the difference of materials in RECY compared to BAU.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Other*	***Total***
MFA BAU (kg)	11.377	4.904	1.166	176	2.512	85	**20.221**
MFA RECY (A) (kg)	11.376	4.885	1.169	176	2.514	85	**20.205**
MFA RECY (B) (kg)	11.343	4.519	1.234	176	2.549	85	**19.906**
MFA RECY (C) (kg)	11.324	4.622	1.274	2.376	2.512	85	**22.192**
MFA RECY (D) (kg)	11.322	4.602	1.277	2.376	2.514	85	**22.176**
MFA RECY (E) (kg)	11.289	4.236	1.342	2.376	2.550	85	**21.877**

Table 14: Material flows in the recycling scenario.

[4] The SF is a value that ranges from 0 to 1 and describes how much useable material comes out of a waste management system. For example, landfill has SF = 0 and reuse has SF = 1. The SF of recycling depends on technical limitations of the material being recycled and the infrastructure in place.

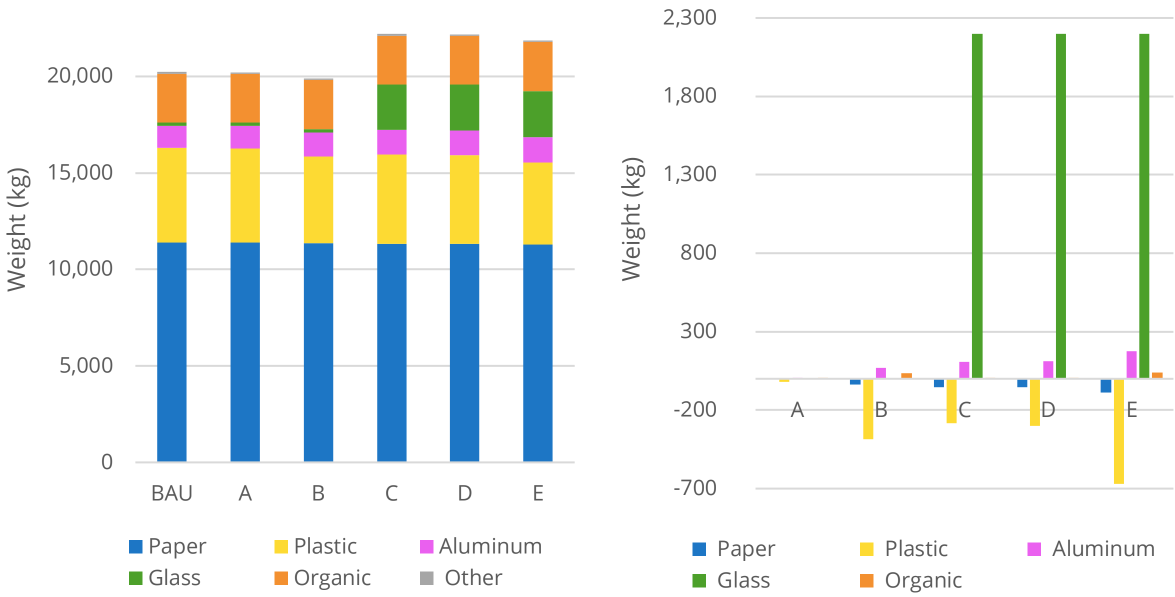

Figure 18: Material flows (left) and material flow difference of the recycle scenario compared with the business-as-usual scenario (right).

The results show that all measures successfully decrease the plastic stream, but this decrease comes at a price. The backstage changes reduce the plastic stream by 6% while drastically increasing the glass stream fourteen-fold. The plastic-free store reduces the plastic stream by a minimum of 0,5% and a maximum of 8%, while only slightly increasing the aluminum and organic streams.

The zero-waste index of RECY is depicted in Table 15, excluding infrastructure. The ZWI is unaltered when only the plastic-free store is implemented, but it slightly increases with the backstage measures. Interestingly, the ZWI of plastic worsens when the backstage measures are implemented. That is because, in this variation, the reusable plastic cups are substituted with single-use aluminum ones. Additionally, there is no plastic backstage, and all the plastic flowing on-site is subject to cross-contamination. Figure 19 illustrates that more materials are recycled in variations C, D, and E than in BAU, but only because more materials are flowing in the festival. Since this increase is mostly glass (see Figure 18), a material with a very high SF and unaffected by cross-contamination, the ZWI increases. However, even if more materials are recycled, the overall losses hardly change. Variation B has the lowest material losses, 4% less than BAU, and variation C has the highest, 0,4% more than BAU.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	***Total***
ZWI BAU	0,88	0,64	0,88	0,98	0,92	**0,82**
ZWI RECY (A)	0,88	0,64	0,88	0,98	0,92	**0,82**
ZWI RECY (B)	0,88	0,64	0,88	0,98	0,92	**0,83**
ZWI RECY (C)	0,88	0,63	0,88	0,98	0,92	**0,84**
ZWI RECY (D)	0,88	0,63	0,88	0,98	0,92	**0,84**

ZWI RECY (E)	0,88	0,63	0,88	0,98	0,92	**0,84**

Table 15: Zero-Waste index in the recycling scenario.

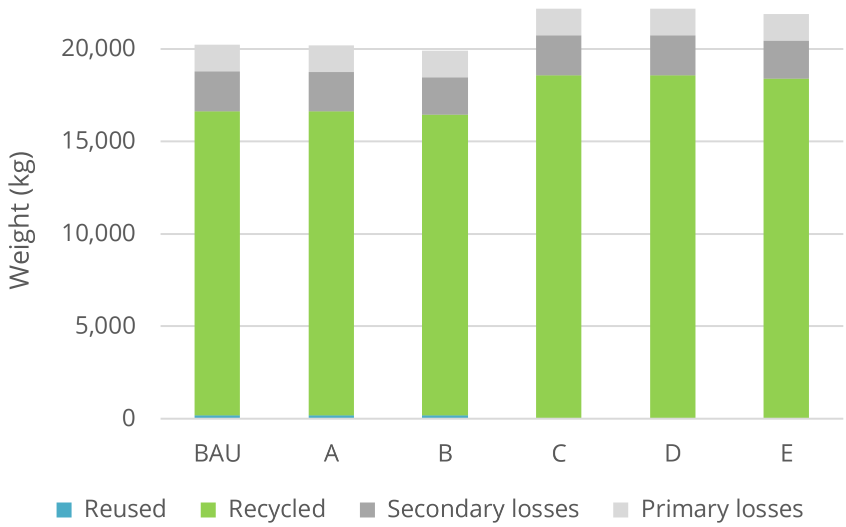

Figure 19: Recycling levels and losses in the recycling scenario.

The carbon footprint of RECY is depicted in Table 16 and illustrated in Figure 20 (left). Figure 20 (right) illustrates how the CF of RECY differs from BAU. The results show that the plastic-free store successfully decreases the CF of Bioritme, even when only a small portion of the audience uses it. The backstage changes increase the CF mainly because of the higher use of glass. We assumed that the glass used in Bioritme was virgin, and since it is a very energy-intensive raw material, the higher use of glass significantly raises the emissions of the festival. If recycled glass were used instead, the CF of variations C, D, and E would substantially decline.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	***Other***	***Total***
CF BAU ($kgCO_2eq$)	31.544	29.268	3.834	93	822	48	**65.609**
CF RECY (A) ($kgCO_2eq$)	31.537	29.218	3.825	93	823	48	**65.545**
CF RECY (B) ($kgCO_2eq$)	31.416	28.277	3.658	93	834	48	**64.328**
CF RECY (C) ($kgCO_2eq$)	31.406	28.390	4.200	1.261	822	48	**66.126**
CF RECY (D) ($kgCO_2eq$)	31.400	28.340	4.191	1.261	823	48	**66.062**
CF RECY (E) ($kgCO_2eq$)	31.279	27.399	4.024	1.261	835	48	**64.845**

Table 16: Carbon footprint of each material stream in the recycling scenario.

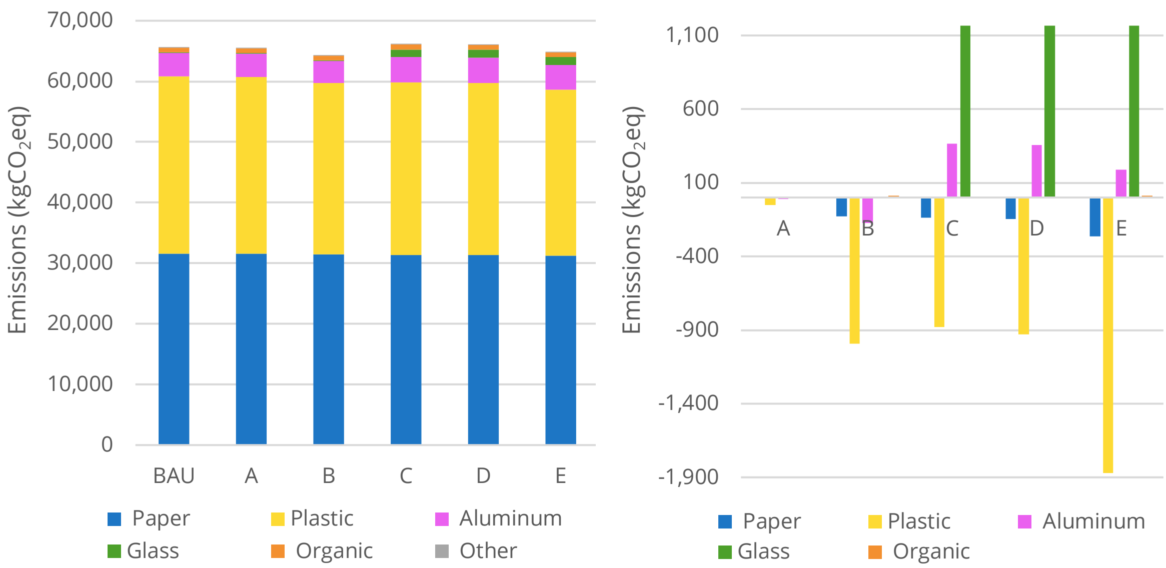

Figure 20: Carbon footprint (left) and carbon footprint difference of the recycle scenario compared with the business-as-usual scenario (right).

Table 17 shows the water footprint of the materials brought by the festival in RECY, illustrated in Figure 21 (left). Even though the WF of the products brought by attendees could not be calculated due to lack of data, the values of the table also consider the products substituted with the plastic-free store (hence the negative values). Figure 21 (right) shows how the WF of RECY differed from BAU. The results show that the plastic-free store reduces the WF of the festival, but the backstage measures increase it (because of the higher use of virgin glass, which is very water-intensive). If recycled glass were used instead, the WF of variations C, D, and E would decline.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Other*	*Direct water*	***Total***
WF BAU (m^3)	731	11	2	20	131	unknown	9	**904**
WF RECY (A) (m^3)	729	10	2	20	131	unknown	9	**901**
WF RECY (B) (m^3)	694	-8	3	20	140	unknown	9	**858**
WF RECY (C) (m^3)	674	0	3	278	131	unknown	9	**1.095**
WF RECY (D) (m^3)	672	-1	3	278	131	unknown	9	**1.093**
WF RECY (E) (m^3)	637	-19	5	278	140	unknown	9	**1.050**

Table 17: Water footprint of the materials brought by the festival in the recycling scenario.

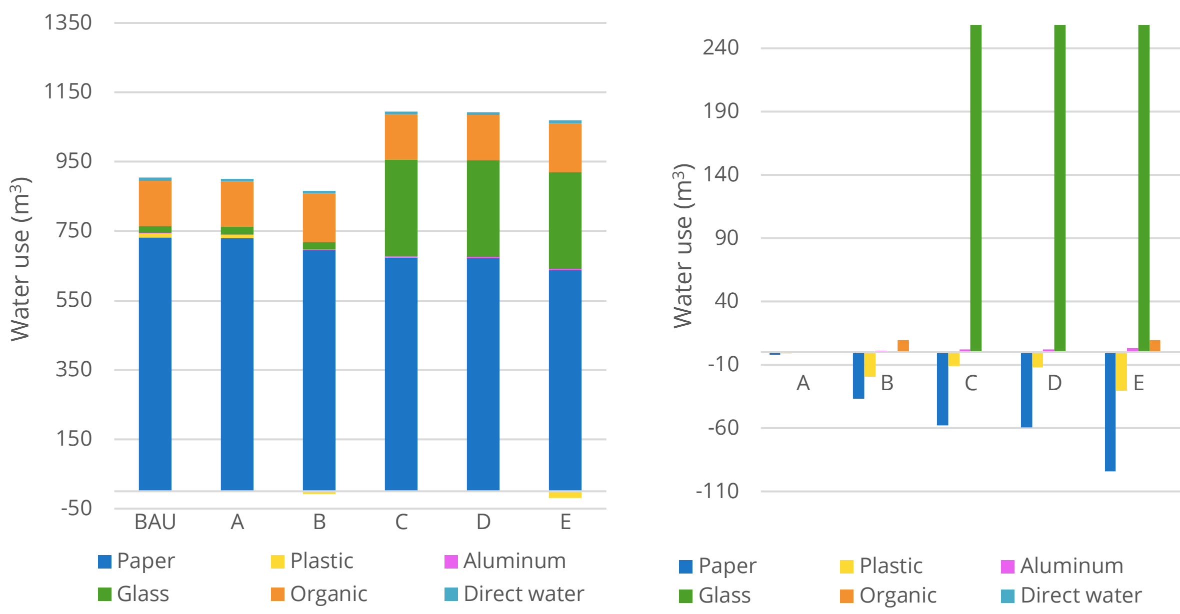

Figure 21: Water footprint (left) and water footprint difference of the recycle scenario compared with the business-as-usual scenario (right).

5.3.2 Sorting scenario

In this scenario, instead of changing the materials flowing in the festival, we changed the efficiency of sorting (as explained in Section 4.4.2, Table 7). Figure 22 illustrates how the cross-contamination rates change when 10%, 30%, and 50% of the bins on-site are staffed (i.e., with volunteers helping people sort their waste). The results show that cross-contamination reduces proportionally to the number of staffed bins.

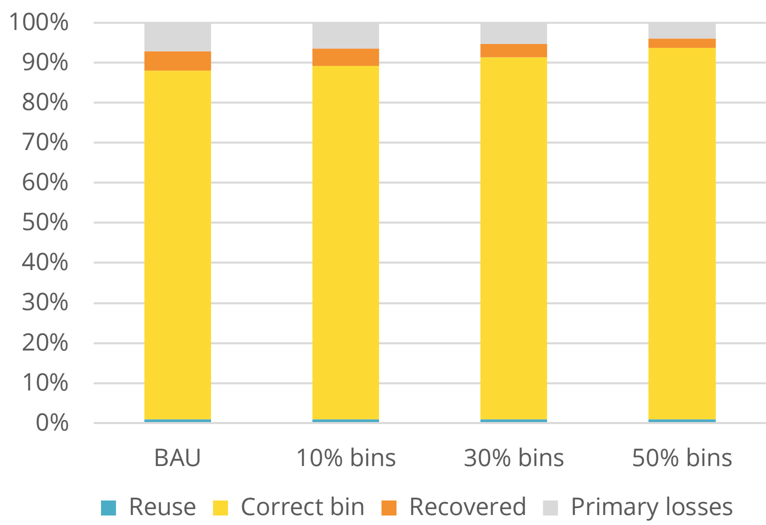

Figure 22: Reuse, sorting, and recovery levels of the waste in the sorting scenario.

The ZWI values are shown in Table 18. With higher collection rates, the recycled materials increase, and so does the ZWI. Figure 23 shows the secondary and primary losses in SORT. Although the secondary losses increase when more materials go to recycling plants, the overall losses decrease by nearly 200kg, 370kg, and 600kg in each variation, respectively. From these results, it is important to highlight that, even with perfect sorting, recycling always produces secondary losses.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	***Total***
ZWI BAU	0,88	0,64	0,88	0,98	0,92	**0,82**
ZWI SORT 10%	0,88	0,65	0,89	0,98	0,93	**0,83**
ZWI SORT 30%	0,90	0,65	0,89	0,98	0,94	**0,84**
ZWI SORT 50%	0,91	0,66	0,90	0,98	0,96	**0,85**

Table 18: Zero-Waste index in the sorting scenario.

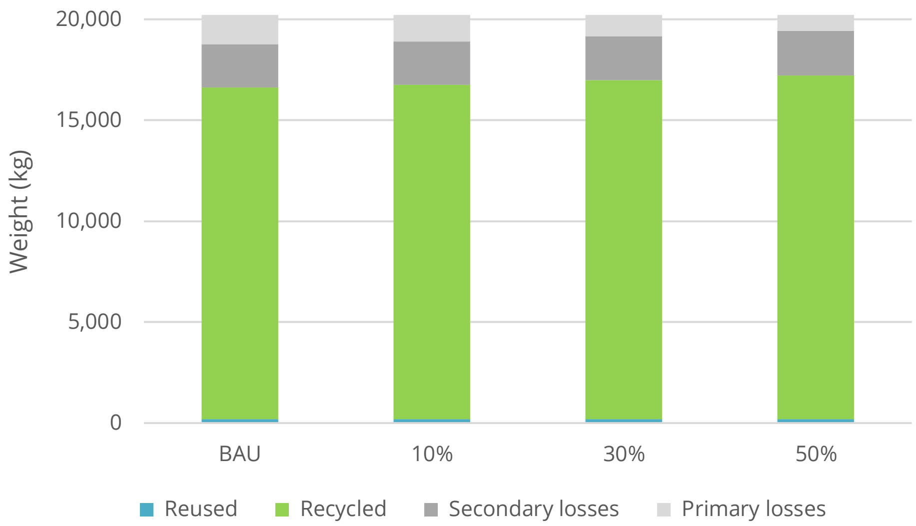

Figure 23: Reuse and recycling levels, primary losses, and secondary losses of each material stream in the business-as-usual and sorting scenarios

The CF, depicted in Table 19, also decreases as sorting improves. Less GHG is emitted in landfills and incineration, and more emissions are avoided due to recycling (and reducing virgin material extraction). The WF values shown in Table 20 only refer to the materials brought by the festival. Since most of these materials were handled backstage, the changes in collection rates on-site do not alter the WF.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Other*	***Total***
CF BAU (kgCO_2eq)	31.544	29.268	3.834	93	822	48	**65.609**
CF SORT 10% (kgCO_2eq)	31.370	29.230	3.777	93	811	48	**65.330**
CF SORT 30% (kgCO_2eq)	31.023	29.155	3.663	93	790	48	**64.772**
CF SORT 50% (kgCO_2eq)	30.675	29.080	3.549	93	769	48	**64.214**

Table 19: Carbon Footprint in the sorting scenario.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Other*	***Direct water***	***Total***
WF BAU (m^3)	731	11	2	20	131	Unknown	**9**	**904**
WF SORT 10% (m^3)	731	11	2	20	131	Unknown	**9**	**904**
WF SORT 30% (m^3)	731	11	2	20	131	Unknown	**9**	**904**
WF SORT 50% (m^3)	731	11	2	20	131	Unknown	**9**	**904**

Table 20: Water Footprint in the sorting scenario.

5.3.3 Reuse scenario

The measures of this scenario (explained in Section 4.4.3, Table 8) were combined into five different variations: in A and B, a package-free store is implemented, and people can bring their own coffee cups and cutlery from home. Both measures have an uptake of 3% (A) and 50% (B). In C, the festival changes some single-use products with refillable ones backstage. D and E combine A+C and B+C, respectively. Table 21 depicts the material flows in REU, illustrated in Figure 24 (left). In order to show the difference between variations more clearly, we zoomed in on the top of the bar plot in Figure 24 (right). In Figure 25, we show how the material streams of REU differed from BAU.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Other*	***Total***
MFA BAU (kg)	11.377	4.904	1.166	176	2.512	85	**20.221**
MFA REU (A) (kg)	11.374	4.897	1.166	176	2.509	85	**20.206**
MFA REU (B) (kg)	11.302	4.750	1.166	176	2.459	85	**19.938**
MFA REU (C) (kg)	11.374	4.906	1.076	177	2.512	85	**20.131**
MFA REU (D) (kg)	11.371	4.898	1.076	177	2.509	85	**20.117**
MFA REU (E) (kg)	11.299	4.752	1.076	177	2.459	85	**19.849**

Table 21: Material flows in the reuse scenario.

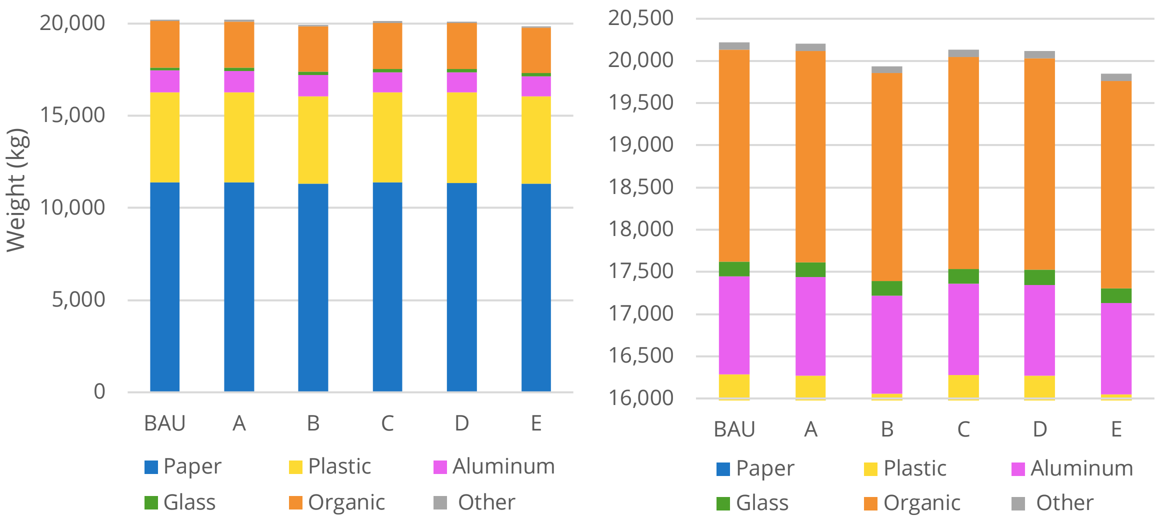

Figure 24: Material flows in the reuse scenario.

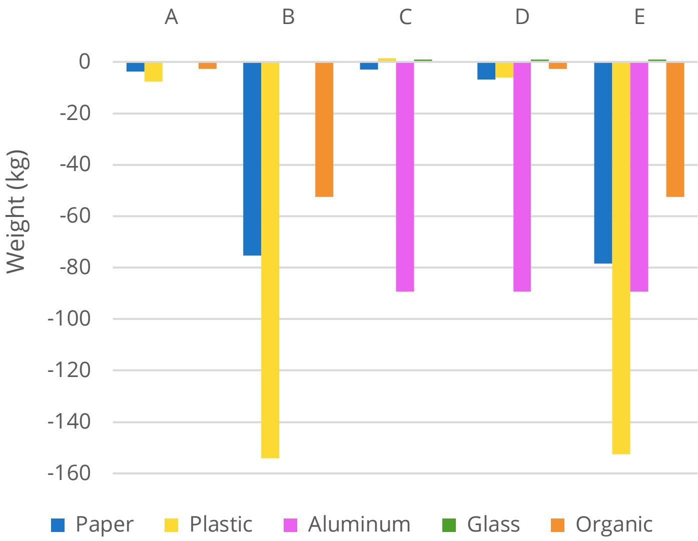

Figure 25: Material flow difference of the reuse scenario compared with the business-as-usual scenario.

The results show an overall reduction of materials in all variations. The changes backstage alone achieve a total material reduction of 7%. A maximum reduction of 13% is reached when the changes backstage are combined with half of the audience's behavioral changes. The most reduced materials are plastic, aluminum, and paper. That is because of the smaller amount of plastic bottles and soft-drink cans used backstage and the avoided cardboard food packaging from the attendees.

The ZWI of REU is depicted in Table 22, and Figure 26 (left) illustrates how the recycling, losses, and reuse rates vary in REU. Again, we zoomed in on the top of the bar plot for clarity in Figure 26 (right). Although the waste reduces and reuse increases, the ZWI does not change in any of the five variations of REU. That is because the increase of reusable materials is not significant enough (only 1kg of reusable sugar glass jars). The change of take-home reusable cups to returnable cups does not change the ZWI because both options are reusable. Moreover, this index evaluates the number of recovered materials from waste (i.e., recycled or reused). Hence, reducing the waste by offering a package-free store or incentivizing BYO bottles does not alter the ratio of recovered waste over the total.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	***Total***
ZWI BAU	0,88	0,64	0,88	0,98	0,92	**0,82**
ZWI REU (A)	0,88	0,64	0,88	0,98	0,92	**0,82**
ZWI REU (B)	0,88	0,64	0,88	0,98	0,92	**0,82**
ZWI REU (C)	0,88	0,64	0,87	0,98	0,92	**0,82**
ZWI REU (D)	0,88	0,64	0,87	0,98	0,92	**0,82**
ZWI REU (E)	0,88	0,64	0,87	0,98	0,92	**0,82**

Table 22: Zero-waste index in the reuse scenario.

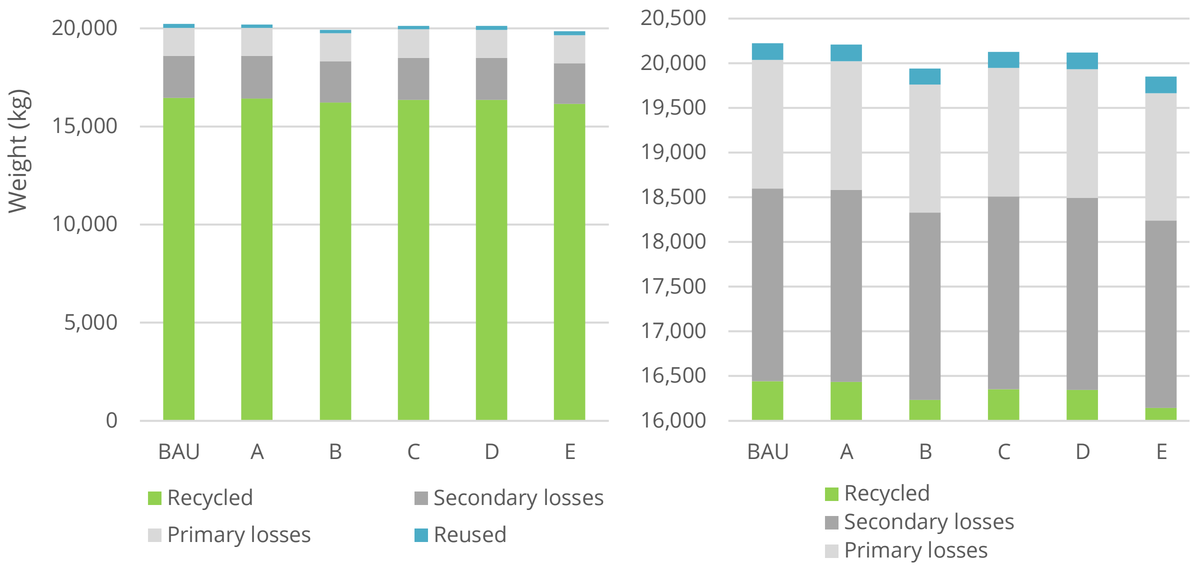

Figure 26: Sorting, reuse, and recovery levels of the waste in the business-as-usual and reuse scenarios.

Despite the constant ZWI, this scenario shows the most significant reduction of emissions, depicted in Table 23 and illustrated in Figure 27 and Figure 28. With the package-free store, a maximum of 2% emission reduction is achieved, and with only the backstage changes, the emissions also decrease by 2%. In combination, REU has the potential of reducing over 1.500 $kgCO_2eq$, 5% of the GHG emissions in BAU. The main contributor to this decline is plastic reduction due to the package-free store and the BYO water bottles.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Other*	***Total***
CF BAU ($kgCO_2eq$)	31.544	29.268	3.834	93	822	48	**65.609**
CF REU (A) ($kgCO_2eq$)	31.538	29.238	3.834	93	821	48	**65.572**
CF REU (B) ($kgCO_2eq$)	31.425	28.671	3.834	93	805	48	**64.876**
CF REU (C) ($kgCO_2eq$)	31.542	28.666	3.646	93	822	48	**64.817**
CF REU (D) ($kgCO_2eq$)	31.536	28.636	3.646	93	821	48	**64.781**
CF REU (E) ($kgCO_2eq$)	31.423	28.069	3.646	93	805	48	**64.084**

Table 23: Carbon footprint in the reuse scenario

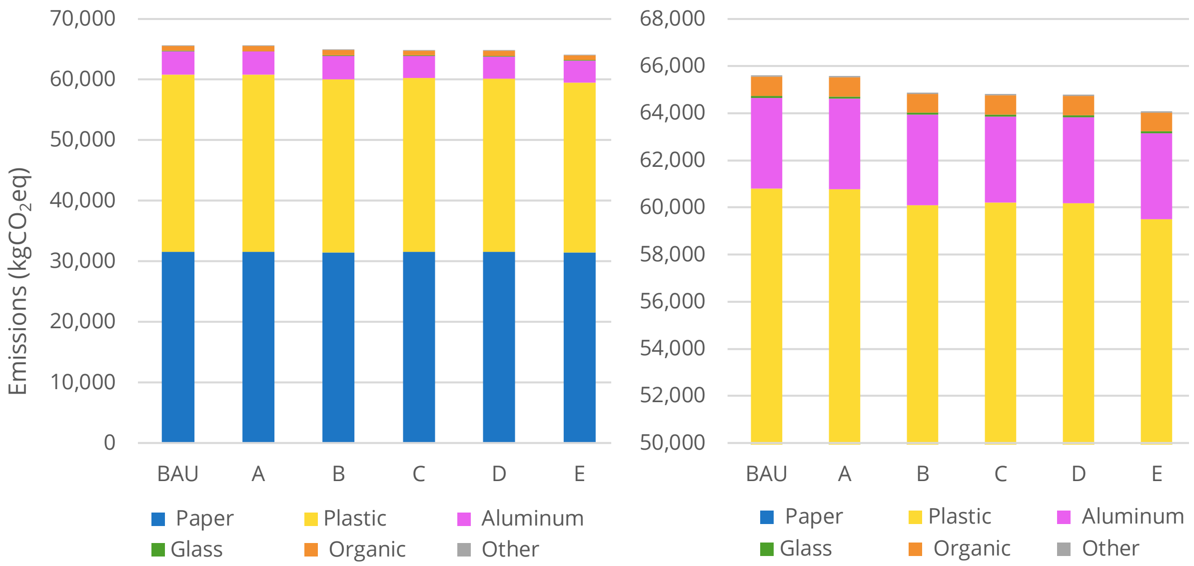

Figure 27: Carbon footprint of the reuse scenario.

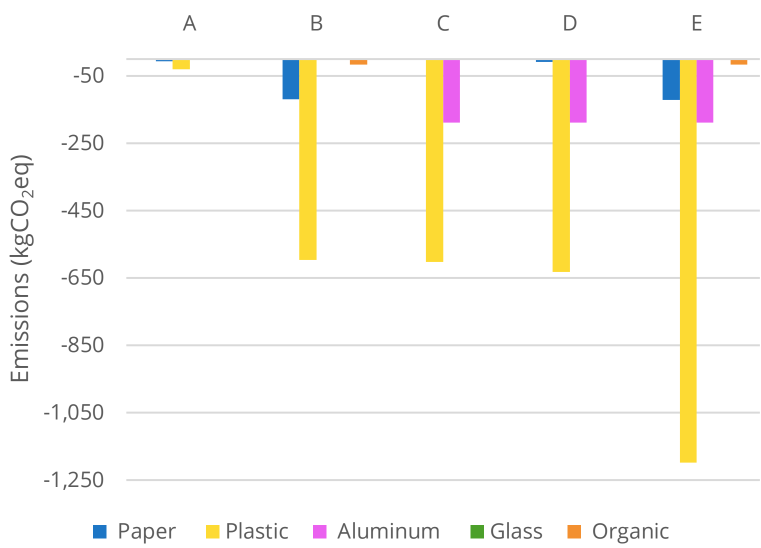

Figure 28: Carbon footprint difference of the reuse scenario compared with the business-as-usual scenario.

Again, this scenario shows the most considerable WF reduction in all scenarios, depicted in Table 24 and illustrated in Figure 29 (left). Figure 29 (right) shows how the WF of REU differs from BAU. These values account for the materials brought by the festival and the products avoided with the package-free store. When many attendees change their behavior (variations B and E), the WF decreases by over 100m^3. The biggest reduction is in the paper and organic streams: on the one hand, fewer people bring food from home packaged in cardboard (a very water-intensive material), and on the other hand, the use of disposable compostable plastic cutlery and coffee cups declines. The backstage measure of substituting canned soft drinks with carbonated water and syrup increases the direct water use, but it is compensated with the reduction of aluminum.

	Paper	*Plastic*	*Aluminum*	*Glass*	*Organic*	*Other*	***Direct water***	***Total***
WF BAU (m^3)	731	11	2	20	131	Unknown	**9**	**904**
WF REU (A) (m^3)	727	11	2	20	129	Unknown	**9**	**897**
WF REU (B) (m^3)	652	6	2	20	94	Unknown	**9**	**782**
WF REU (C) (m^3)	728	9	0	20	131	Unknown	**10**	**898**
WF REU (D) (m^3)	724	9	0	20	129	Unknown	**10**	**892**
WF REU (E) (m^3)	649	3	0	20	94	Unknown	**10**	**777**

Table 24: Water footprint of the materials brought by the festival in the reuse scenario.

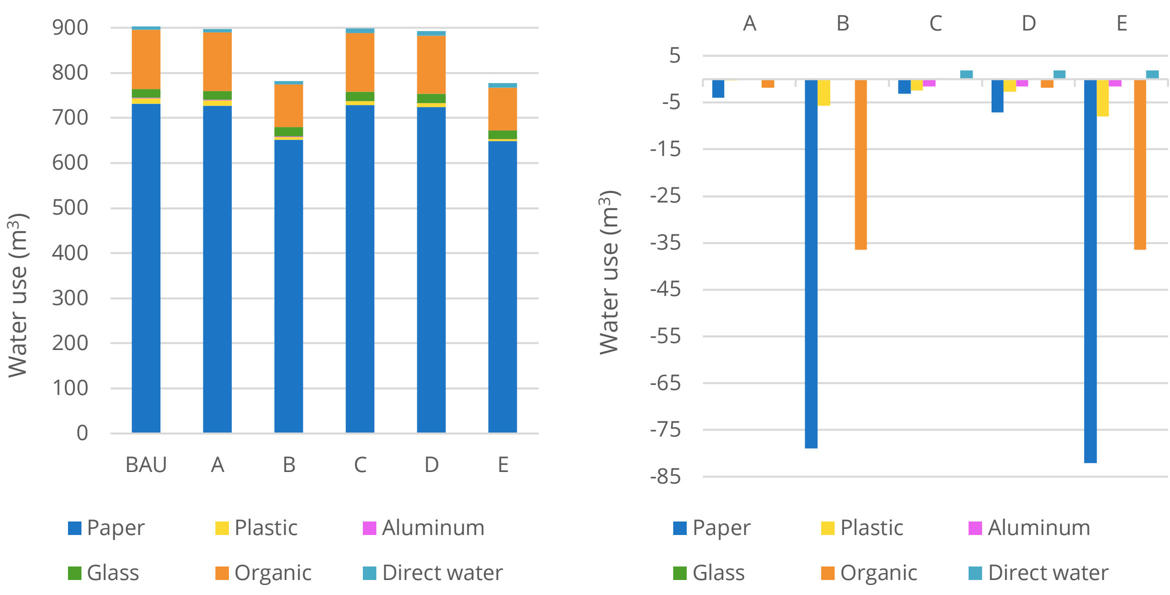

Figure 29: Water footprint (left) and water footprint difference of the reuse scenario compared with the business-as-usual scenario (right).

5.4 Scenarios' overview

A summary of the values of BAU, RECY, SORT, and REU are depicted in Table 25, indicating which variations outperformed BAU (in green) and which ones fell behind (in red). The bold values indicate the extremes. This table excludes infrastructural elements and includes direct water use.

	BAU	RECY (A)	RECY (B)	RECY (C)	RECY (D)	RECY (E)	SORT (10%)	SORT (30%)	SORT (50%)	REU (A)	REU (B)	REU (C)	REU (D)	REU (E)
Materials flowing (kg)	20.221	20.205	19.906	**22.192**	22.176	21.877	20.221	20.221	20.221	20.206	19.938	20.131	20.117	**19.849**
Reuse (kg)	180	180	180	0	0	0	180	180	180	180	180	**181**	**181**	**181**
Sent to recycling (kg)	18.597	18.580	18.250	**20.745**	20.728	20.398	18.728	18.989	19.250	18.584	18.330	18.507	18.493	**18.240**
Lost (kg)	1.443	1.443	1.436	**1.447**	1.446	1.439	1.313	1.052	**791**	1.443	1.428	1.443	1.442	1.428
ZWI	0,82	0,82	0,83	0,84	0,84	0,84	0,83	0,84	**0,85**	0,82	0,82	**0,82**	0,82	0,82
CF ($kgCO_2eq$)	65.609	65.545	64.328	**66.126**	66.062	64.845	65.330	64.772	64.214	65.572	64.876	64.817	64.781	**64.084**
WF (m^3)	904	901	858	**1.095**	1.093	1.050	904	904	904	897	782	898	892	**777**

Table 25: Impacts of all the simulated scenarios in comparison to the business-as-usual.

The findings suggest that Bioritme is on the right track to achieve the zero-waste goal, indicated by the high zero-waste index (ZWI) in 2019, which was 0,93 (including infrastructure). The ZWI shows how much virgin material extraction is avoided thanks to the way waste is treated. The high value of ZWI is partly because the infrastructure was almost entirely reused or rented. When infrastructure is left out of the equation, the ZWI drops to 0,82. A lower ZWI means that there is a higher proportion of materials lost over the total.

Moreover, most of the materials flowing on-site are not brought by the festival but by the audience (see Table 9 in Section 4.2). Research on municipal waste separation levels has found that people's socio-economic background –such as age and income– influences waste disposal behavior (Al-Khatib, Arafat, Daoud, & Shwahneh, 2009; De Feo & De Gisi, 2010). Bioritme's audience is generally very young and without a steady income (students) and may be looking to save money by bringing food and drinks from home (with the corresponding packaging). Hence, any waste reduction and recycling measures will have to engage with the audience actively and fit their needs and limitations.

All in all, this research showed that for a festival's waste management system to minimize virgin material use, emissions, and water, it must: (i) reduce the products sold (e.g., water fountains instead of plastic bottles in REU), (ii) reuse products as much as possible (e.g., returnable plastic cups in REU), (iii) if products must be disposable, offer only highly recyclable disposables (e.g., aluminum cans instead of plastic bottles in RECY), (iv) ensure proper sorting (e.g., by staffing bins in SORT), and (v) communicate and actively engage the audience in waste management plans (e.g., by incentivizing plastic- or package-free groceries in RECY and REU). An 'ideal' scenario in Bioritme considering all of the above would have the results in Table 26. Indeed, all impact categories in this scenario are reduced in comparison to BAU. The ZWI is the highest, and the CF is the smallest amongst the other three scenarios. The WF is slightly higher than REU (E), but it is still considerably lower than BAU. The ideal scenario proposed matches what associations and festivals at the forefront of event sustainability advocate (Metabolic, 2018; van de Voort & Schurink, 2018).

	BAU	IDEAL
Materials flowing (kg)	20.221	19.719
Reuse (kg)	180	181
Sent to recycling (kg)	18.597	18.634
Lost (kg)	1.443	790
ZWI	0,82	0,86
CF (kgCO_2eq)	65.609	62.029
WF (m^3)	904	812

Table 26: Impacts of the ideal scenario in comparison to business-as-usual.

6. Discussion

This chapter discusses the implications of the research findings for the music festival sector, its limitations, and future research avenues in the field of zero-waste events and their impacts.

6.1 Research implications

The methodology proposed in this research can be used to evaluate the environmental impact of the waste management system of other events besides music festivals, as long as they have access to information about the materials brought in, the waste collected, and the characteristics of the municipal waste system. Moreover, our findings can be applied to other festivals or events striving to address the issue of their waste. To increase the ZWI and get closer to the zero-waste goal, material losses must be minimized. Material losses happen because of incorrect sorting (primary losses) and the recycling process's technical limitations (secondary losses). This research found that better sorting and a focus on reuse and waste avoidance can effectively reduce the carbon and water footprints of a music festival, which adheres to the waste management hierarchy (European Commission, n.d.). Contrary to public belief, substituting disposable plastic products with disposable products made from other materials can worsen an event's carbon and water footprints. Hence, a better approach to phasing out disposable plastic products would be to either eliminate them when possible or else substitute them with reusable alternatives.

Taking a step back and looking at the bigger picture, it becomes apparent that 'zero-waste' does not necessarily translate into 'environmentally friendly'. Despite the promising definition of zero-waste as the "conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials" (ZWIA, 2018), zero-waste fails to address what happens when the consequences of conserving resources outweigh the consequences of consuming them. For instance, compostable plastics are made with renewable sources and can return to the soil as compost, conserving resources. However, compared to conventional plastics, they require larger quantities of freshwater to be produced, induce monoculture practices, and lead to food price increases (Gironi & Piemonte, 2011; Morão & de Bie, 2019). By extension, the Zero-Waste Index (ZWI) should not be used as a stand-alone indicator to compare the environmental performance of different waste management systems. While the ZWI is a useful indicator to evaluate resource depletion potential, our findings suggest that it should be paired up with a tool that shows how the material flows change in a system to account for any material reduction or avoidance (such as MFA) and other environmental impact indicators relevant to the system under study.

6.2 Limitations

The findings of this research were almost entirely based on a Material Flow Analysis. The data that built the MFA came from various sources: provided by Bioritme, from academic publications, and from gray literature. The diversity of information sources makes the results inherently uncertain (Laner, Rechberger, & Astrup, 2014), and the sometimes poor quality of the data adds to that uncertainty.

Regarding Bioritme's data, it was incomplete, and most of it (if not all) had to be estimated by the organizers two years after the event took place. Several critical assumptions had to be made due to a lack of data and/or estimations. Nonetheless, the reasoning behind all the assumptions is explained in detail in the method, and the formulas could be adapted if more precise data were available. One assumption that particularly impacted the results was that the proportion of each material in the waste collected was equivalent to the proportion of material sold by the festival. Since almost all the products sold by the festival were recyclable, the residual waste stream constituted an insignificant fraction in our calculations, while other research has found it to be the largest waste stream in festivals (Cierjacks et al., 2012; Martinho et al., 2018). Moreover, there was no record of the food sold at the festival. Food consumption is a big contributor to the carbon and water footprints of the planet (OECD, 2016; Zhan-Ming & Chen, 2013), and it is fair to presume that it would have had a significant impact on Bioritme's footprints as well. In Section 6.3 we propose how the food stream could have been added to the MFA if more data would have been available.

Concerning the literature data, we struggled to find specific emissions and water use factors of the life phases of raw material extraction, manufacturing, and waste treatment. In most cases, the emissions or water use factors referred to the product's whole life cycle or only one of the life cycle phases. Identifying the phase responsible for a certain environmental impact is critical to evaluate the potential of a waste management system. For instance, recycling can avoid raw material extraction. Therefore, it potentially reduces the environmental impacts of the products that have impactful raw material extraction, while products with an impactful manufacturing phase will not benefit from recycling so much. Water use factors of non-agricultural materials were particularly scarce, and hence the water footprint results must be assessed with caution.

Moreover, some of the values we used were generalized for simplicity, adding to the uncertainty of the results: First, all the waste was considered to be treated in Catalonia. However, according to the Agència de Residus de Catalunya[5], a big part of the waste in Catalonia is treated elsewhere (ARC, 2020b), which means that the substitution factors (SF) and environmental impacts may differ. Second, the SFs were generalized per material stream and not to the characteristics of each specific material. For instance, all plastic was considered to have the same SF when in reality, some plastics are more recyclable than others (Ellen MacArthur Foundation et al., 2016). The SF indicates how much useful material comes out of a waste management subsystem. For example, in the case of plastic recycling, it indicates how much recycled plastic outputs from recycling 1kg of plastic waste. This value considerably influences the ZWI calculation, and therefore it must come from a reliable source. For our research, we used the SFs provided by the Agència de Residus de Catalunya (Inèdit & ARC, 2021), but they may not always be so readily available. In such cases, the SF of each material will need to be estimated through extensive research about the recycling technologies in place.

6.3 Future research

[5] In English: Catalan Agency of Waste

Based on the discussion and limitations of the research, we propose some future research avenues for researchers who would be interested in continuing our work and expand the knowledge on zero-waste events and their implications. Since good data is a critical bottleneck for any MFA, future research could aim to solve this issue. Possible ways to do this would be to characterize the input and waste data of a festival manually or develop a standardized methodology for festivals to measure it themselves. Future studies on other festivals will also want to make sure they have access to food data. To integrate it into the MFA, we propose the following:

The organic bins in the kitchens could be assumed to contain only unavoidable waste (e.g., eggshells, paprika cores, chicken bones), which can be estimated by multiplying the amount of food sold by a percentage of unavoidable food waste ($\%_{unavoid}$) (equation 25). The percentage of unavoidable food waste varies greatly depending on the meals served. A possible value for this percentage can be extracted from the findings of Betz, Buchli, Göbel, and Müller (2015) in a study of an office canteen in Switzerland, where 21% of the total food wasted was unavoidable waste from meal preparation. Organic bins on-site could be assumed to contain avoidable food waste from the meals served and unavoidable and avoidable food waste brought by the attendees (equation 26). The percentage of avoidable food waste from the meals sold ($\%_{avoid}$) can again be extracted from the findings of Betz et al. (2015), where 24% of the total food waste collected was avoidable waste from the plates.

$$OUT_{bin_{kitchen}}^{food} = IN_{sold}^{food} \cdot \%_{unavoid} \tag{25}$$

$$OUT_{bin_{onsite}}^{food} = IN_{sold}^{food} \cdot \%_{avoid} + OUT_{attd}^{food} \tag{26}$$

On another note, we found that the audience of a festival plays a vital role in the characteristics of the waste and sorting levels of an event. Hence, it is of utmost importance to have them on board in any waste reduction plans. Future research could focus on audience engagement strategies that effectively shape people's consumption and waste disposal behavior in events. Special attention should be paid to the needs and limitations of the audience's demographics since factors such as age and income can influence how people respond to waste management measures. Another avenue for future research could be the social and economic implications of zero-waste management systems in festivals. One possible way to do so would be to find the economic implications of zero-waste management systems by underlining the monetary value of material recovery, GHG reduction, and water savings, as proposed by Zaman and Swapan (2016).

7. Conclusions

Music festivals create loads of solid waste, often dumped in landfills or burned, contributing to resource depletion, water, air, and soil pollution. The zero-waste goal presents itself as an aspirational target that music festivals can strive for in their battle against waste. This goal advocates for switching the perspective of waste as a problem to waste as a resource, capturing the value of materials and minimizing losses by reducing, reusing, repairing, or recycling materials. In this research, we have explored the consequences of aiming at the zero-waste goal in festivals by asking ourselves the following question: "*What are the environmental implications of Zero-Waste Management Systems in music festivals?*". To answer the question, we used data from the case study music festival Bioritme, in Spain. First, we analyzed the business-as-usual situation of the festival by performing a Material Flow Analysis, calculating how close the festival was to the zero-waste goal with the Zero-Waste Index (ZWI), and measuring the Carbon and Water Footprints of the materials and waste management system in place. Next, we compared the business-as-usual values with three scenarios with different waste reduction strategies: focusing on using more recyclable materials, better sorting, and reuse.

The results showed that having a higher ZWI does not necessarily translate into better environmental performance. The zero-waste goal can be achieved with various waste management strategies, and choosing the most environmentally friendly one requires combining the ZWI with other environmental indicators. From the simulated scenarios, we found that the least impactful waste management system (WMS) for Bioritme would reduce the products used and sold, switching to reusable products whenever possible, and, if disposables cannot be avoided, only offering highly recyclable disposables. Moreover, it would ensure that waste was properly sorted on-site and actively engage the audience in the waste reduction plans. These results can be applied to other similar events such as sporting events, conferences, or weddings.

As with any other study based on an MFA, the results are heavily bound to the quality of the data (both from the festival and literature). Better data collection on-site and improved emission and water use databases can facilitate future research on the topic of zero-waste and environmentally friendly events. The vital role that the audience plays in reducing waste in festivals also opens avenues of further research, focusing on strategies to change the consumption behavior of young people with limited income (students) in a festive context. More research is also needed to evaluate the social and economic impacts of zero-waste festivals.

The COVID-19 pandemic has helped us all value the importance of social gatherings and leisure, but the return of festivals should not go at the expense of a healthy planet. Aiming at the zero-waste goal can help identify underlying problems in the way resources are managed in a festival (i.e., the type of products sold, collection efficiency, and waste treatment), guiding the redesign of its WMS towards more environmentally friendly practices. However, it is crucial that the organization works closely with the audience and actively involves them. Just like the late philosopher Marshall McLuhan said, "There are no passengers on Spaceship Earth. We are all crew".

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Appendix A

MFA parameters: weight per unit, units sold, uses, and total products sold and reused

Material	*Product*	*Weight/unit (kg/unit)*	*Units sold*	*Uses*	*IN_{sold} (kg)*	*IN_{reuse} (kg)*	*Source*
Aluminum	Cans 0,33l	0,01	6.000,00	1,00	89,40	-	(Recycle USA, 2014)
Aluminum	Foil	0,02	2,00	1,00	0,03	-	(AZO materials, 2002)
Glass	Bottles 0,33l	0,21	250,00	1,00	51,25	-	(Vetropack, n.d.-b)
Glass	Bottles 0,7l	0,57	220,00	1,00	124,52	-	(Vetropack, n.d.-a)
Organic	PLA Cutlery	0,00	4.200,00	1,00	18,06	-	(Shalbaida, n.d.)
Organic	Compostable plates	0,01	4.000,00	1,00	52,00	-	(Enviropack, n.d.)
Organic	Napkins	0,00	12.000,00	1,00	48,00	-	(CPC, 2014)
Organic	Paper & PLA cups (200ml)	0,01	5.000,00	1,00	35,00	-	(Cuplandia, n.d.)
Organic	Kitchen paper	0,20	8,00	1,00	1,63	-	(Miller, 2019)
Other	Ropes	Unknown	-	15,00	-	75,00	-
Other	Wine box lining 5l	0,01	70,00	1,00	0,70	-	(Liquibox Packaging, n.d.)
Other	PA/EVOH/PE Vacuum plastic	0,00	2.000,00	1,00	2,86	-	(Wójtowicz, 2018)
Other	PVC Tents	Unknown	-	15,00	-	64,00	-
Other	Shade tents	Unknown	-	15,00	-	60,00	-
Other	Stage	Unknown	-	15,00	-	26.000,00	-
Other	Straw fences	Unknown	-	15,00	-	500,00	-
Other	PVC signaling	Unknown	-	15,00	-	50,00	-
Paper	Wine box cardboard 15x15x25	0,77	70,00	1,00	53,90		(eSupplyStore, n.d.)
Paper	Rice packaging	0,01	6,00	1,00	0,06	-	(Ta Thi & Thi Anh, 2020)
Paper	Sugar envelope	0,00	6.000,00	1,00	3,00	-	(Chegg Study, n.d.)
Paper	Cardboard boxes 50x50x50	0,84	700,00	1,00	585,90	-	(Jakodan, n.d.)
Paper	Cardboard bins 40x40x70	0,84	50,00	1,00	41,85	-	(Jakodan, n.d.)
Plastic	Cartons	0,03	500,00	1,00	12,50	-	(TetraPack, 2021)
Plastic	Chip bags 170g	0,01	200,00	1,00	1,40	-	(Ecoembes, n.d.-a)

Plastic	PP rigid cups	0,03	6.000,00	1,00	-	180,00	(Ecofestes, n.d.)
Plastic	PET bottles 1,5l	0,03	3.000,00	1,00	90,00	-	(Ecoembes, n.d.-b)
Plastic	PP Straws	0,00	500,00	1,00	0,30	-	(Boonniteewanich, Pitivut, Tongjoy, Lapnonkawow, & Suttiruengwong, 2014)
Plastic	LDPE trash bags	0,00	2.000,00	1,00	8,00	-	(Boustead, 2005)
Water	Ice	Unknown	Unknown	1,00	4.000,00	-	-
Water	Water in bottles of 1,5l	1,50	3.000,00	1,00	4.500,00	-	-
Wood	Decoration	Unknown	Unknown	15,00	-	200,00	-
Wood	Signaling	Unknown	Unknown	15,00	-	500,00	-
Wood	Pallets	31,58	14,25	15,00	450,00	4.700,00	(Tornese, Carrano, Thorn, Pazour, & Roy, 2016)

MFA parameters: waste collected on-site, backstage, and reusable products

Bin	OUT_{site}	$OUT_{backstage}$	OUT_{reuse}	*Source*
Paper	10.000	640	0	Bioritme
Lightweight packaging	10.000	102	180	Bioritme
Glass	0	176	0	Bioritme
Organic	2.000	150	0	Bioritme
Wood	0	450	5.400	Bioritme
Other	2.000	4	26.749	Bioritme

Appendix B

CF parameters: emission factor of raw material extraction, manufacturing, and reuse

Material	*Product*	EF_{raw} *(kgCO2eq/kg)*	EF_{manuf} *(kgCO2eq/kg)*	EF_{reuse} *(kgCO2eq/kg)*	*Source*
Aluminum	Cans 0,33l	12,11	1,84	-	(N. da Silva, d'Souza, & Binder, 2010)
Aluminum	Foil	12,11	1,84	-	(EPA, 2016)
Glass	Bottles 0,33l	0,58	0,52	-	(Ecofys, 2012; EPA, 2016)
Glass	Bottles 0,7l	0,58	0,52	-	(Ecofys, 2012; EPA, 2016)
Organic	PLA Cutlery	2,30	1,87	-	(EPA, 2016; World Centric, 2018)
Organic	Compostable plates	-	1,38	-	(Korbelyiova, 2019)
Organic	Napkins	0,75	3,25	-	(Jelse & Westerdahl, 2011; Ta Thi & Thi Anh, 2020)
Organic	Paper & PLA cups (200ml)	1,89	0,17	-	(Ali, 2018; Benavides, Zare-Mehrjerdi, & Lee, 2019; Ta Thi & Thi Anh, 2020)
Organic	Kitchen paper	0,75	0,33	-	(Jelse & Westerdahl, 2011; Ta Thi & Thi Anh, 2020)
Other	Ropes	unknown	unknown	-	-
Other	Wine box lining 5l	unknown	unknown	-	-
Other	PA/EVOH/PE Vacuum plastic	unknown	unknown	-	-
Other	PVC Tents	unknown	unknown	-	-
Other	Shade tents	unknown	unknown	-	-
Other	Stage	unknown	unknown	-	-
Other	Straw fences	unknown	unknown	-	-
Other	PVC signaling	unknown	unknown	-	-
Paper	Wine box cardboard 15x15x25	0,77	2,54	-	(EPA, 2016; Kathy H. & Gaurav R., 2017)
Paper	Rice packaging	1,36	unknown	-	(Ta Thi & Thi Anh, 2020)
Paper	Sugar envelope	1,36	unknown	-	(Ta Thi & Thi Anh, 2020)
Paper	Cardboard boxes 50x50x50	0,77	2,54	-	(EPA, 2016; Kathy H. & Gaurav R., 2017)
Paper	Cardboard bins 40x40x70	0,77	2,54	-	(EPA, 2016; Kathy H. & Gaurav R., 2017)
Plastic	Cartons	-	1,12	-	(TetraPack, 2021)
Plastic	Chip bags 170g	-	22,50	-	(BBC News UK, n.d.)
Plastic	PP rigid cups	1,52	2,24	-	(EPA, 2016; World Centric, 2018)
Plastic	PET bottles 1,5l	2,35	0,63	-	(Blue, 2018; World Centric, 2018)
Plastic	PP Straws	1,52	0,17	-	(Boonniteewanich et al., 2014)

Plastic	LDPE trash bags	2,70	6,80	-	(Boustead, 2005; Hekkert, Joosten, Worrell, & Turkenburg, 2000)
Water	Ice	n/a	n/a	n/a	-
Water	Water in bottles of 1,5l	n/a	n/a	n/a	-
Wood	Decoration	0,01	0,11	-	(Tornese et al., 2016)
Wood	Signaling	0,01	0,11	-	(Tornese et al., 2016)
Wood	Pallets	0,01	0,11	-	(Tornese et al., 2016)

Appendix C

WF parameters: blue water use and gray water use of raw material extraction, manufacturing, and reuse

Material	*Product*	BWU_{raw} (l/kg)	BWU_{manuf} (l/kg)	GWU_{raw} (l/kg)	GWU_{manuf} (l/kg)	WU_{reuse} (l/kg)	*Source*
Aluminum	Cans 0,33l	16,00	-	7,00	-	-	(Ball Corporation, 2020)
Aluminum	Foil	16,00	-	7,00	-	-	(Ball Corporation, 2020)
Glass	Bottles 0,33l	8,61	95,07	13,70	-	-	(Bonamente et al., 2016; Vetropack, 2020)
Glass	Bottles 0,7l	8,61	95,07	13,70	-	-	(Bonamente et al., 2016; Vetropack, 2020)
Organic	PLA Cutlery	248,00	-	3,80	0,19	-	(International Finance Corporation, 2010; Korol, Hejna, Burchart-Korol, Chmielnicki, & Wypiór, 2019)
Organic	Compostable plates	21,00	830,00	33,00	-	-	(WestRock, 2019)
Organic	Napkins	25,90	1.012,00	31,02	89,40	-	(Klemes, 2015; Ma et al., 2018)
Organic	Paper & PLA cups (200ml)	136,95	506,00	unknown	unknown	-	(Klemes, 2015; Van Oel & Hoekstra, 2010)
Organic	Kitchen paper	1.155,00	-	31,02	89,40	-	(Klemes, 2015; Ma et al., 2018)
Other	Ropes	unknown	unknown	unknown	unknown	-	-
Other	Wine box lining 5l	unknown	unknown	unknown	unknown	-	-
Other	PA/EVOH/PE Vacuum plastic	unknown	unknown	unknown	unknown	-	-
Other	PVC Tents	unknown	unknown	unknown	unknown	-	-
Other	Shade tents	unknown	unknown	unknown	unknown	-	-
Other	Stage	unknown	unknown	unknown	unknown	-	-
Other	Straw fences	unknown	unknown	unknown	unknown	-	-
Other	PVC signaling	unknown	unknown	unknown	unknown	-	-
Paper	Wine box cardboard 15x15x25	25,90	1.012,00	33,00	-	-	(Klemes, 2015; WestRock, 2019)
Paper	Rice packaging	25,90	1.012,00	0,30	10,00	-	(Klemes, 2015; WestRock, 2019)
Paper	Sugar envelope	25,90	1.012,00	0,20	8,00	-	(Klemes, 2015; WestRock, 2019)
Paper	Cardboard boxes 50x50x50	25,90	1.012,00	33,00	-	-	(Klemes, 2015; WestRock, 2019)
Paper	Cardboard bins 40x40x70	25,90	1.012,00	33,00	-	-	(Klemes, 2015; WestRock, 2019)
Plastic	Cartons	unknown	unknown	31,20	-	-	(Li, Ugochukwu, Nordström, & Larsson, 2009)
Plastic	Chip bags 170g	unknown	unknown	unknown	unknown	-	-

Plastic	PP rigid cups	13,70	unknown	3,80	0,19	-	(International Finance Corporation, 2010; Katsoufis, 2009)
Plastic	PET bottles 1,5l	62,00	unknown	10,00	unknown	-	(Olson-Sawyer & Madel, 2020)
Plastic	PP Straws	13,70	-	0,70	0,12	-	(International Finance Corporation, 2010; Katsoufis, 2009)
Plastic	LDPE trash bags	13,10	-	3,80	0,19	-	(International Finance Corporation, 2010; Katsoufis, 2009)
Water	Ice	-	-	1,00	-	-	-
Water	Water in bottles of 1,5l	-	-	1,00	-	-	-
Wood	Decoration	1.206,39	-	unknown	unknown	-	(Schyns, Booij, & Hoekstra, 2017)
Wood	Signaling	1.445,42	-	unknown	unknown	-	(Schyns et al., 2017)
Wood	Pallets	870,70	-	unknown	unknown	-	(Schyns et al., 2017)

Appendix D

User interface of the model in Microsoft Excel

The Excel files with the calculations are available upon request. Each scenario is modelled in a separate file with its corresponding name (BAU, RECY, SORT, REU, and IDEAL). Since some scenarios use data from other scenarios, it is important that all the files are opened at the same time to avoid getting incorrect values. Changing the variation of RECY, SORT, REU, and IDEAL can be done by putting a key word in in the bright yellow cell in the 'MFA' sheet. The file configuration and specific key words for each scenario are indicated in Tables 27-31.

Business-as-usual scenario	
Sheet name	*Content*
Parameters	Parameters of the waste management system in Catalonia, including cross-contamination levels, destination of rest, emission factors, and water use.
MFA	Material Flow Analysis calculations. It includes the list of inputs from the festival, estimated inputs from the attendees, collected waste, and estimated recycling levels and losses.
ZWI	Zero Waste Index calculations. The ZWI is broken down per material stream and with and without infrastructure. In this sheet there are also the values of how much of the waste collected, recycled, and lost was under the responsibility of the festival and the audience
CF	Carbon Footprint calculations. It includes the list of inputs from the festival and their emission factors. The carbon footprint is broken into festival and attendees CF, and per life cycle phase.
WF	Water Footprint calculations. It includes the list of inputs from the festival and their water use factors. The water footprint is only calculated for the materials brought by the festival, and it is broken down into blue and gray water footprints, and per life cycle phase

Table 27: Spreadsheet configuration of BAU.

Recycling scenario	
Sheet name	*Content*
Parameters	Parameters of the waste management system in Catalonia, including cross-contamination levels, destination of rest, emission factors, and water use.
newData	List of inputs of BAU and of the new system, including the new materials backstage (in green) and the items introduced in the plastic-free store (in blue).

MFArecy	Material Flow Analysis calculations. It includes the list of inputs from the festival, estimated inputs from the attendees, collected waste, and estimated recycling levels and losses. The flows of materials avoided with the plastic-free store are detailed as well. To change between variations, the yellow cell must be set to: • Nothing → BAU • "A" or "a" → variation A • "B" or "b" → variation B • "C" or "c" → variation C • "D" or "d" → variation D • "E" or "e" → variation E
ZWI	Zero Waste Index calculations for all the variations. In this sheet there are also the values of how much of the waste collected, recycled, and lost was under the responsibility of the festival.
CF	Carbon Footprint calculations. It includes the list of inputs from the festival and their emission factors, and of the products avoided with the store.
WF	Water Footprint calculations. It includes the list of inputs from the festival and their water use factors, and of the products avoided with the store. The water footprint is only calculated for the materials brought by the festival, but the avoided products are deducted from the total.

Table 28: Spreadsheet configuration of RECY.

Sorting scenario	
Sheet name	*Content*
Parameters	Parameters of the waste management system in Catalonia, including cross-contamination levels, destination of rest, emission factors, and water use.
MFAsort	Material Flow Analysis calculations. It includes the list of inputs from the festival, estimated inputs from the attendees, and the new estimated values of cross-contamination, losses, and recycling. To change between variations, the yellow cell must be set to: • Nothing → BAU • "1" → variation with 10% staffed bins • "2" → variation with 30% staffed bins • "3" → variation with 50% staffed bins
ZWI	Zero Waste Index calculations for all the variations. In this sheet there are also the values of how much of the waste collected, recycled, and lost was under the responsibility of the festival.
CF	Carbon Footprint calculations. It includes the list of inputs from the festival and their emission factors.
WF	Water Footprint calculations. It includes the list of inputs from the festival and their water use factors. The water footprint is only calculated for the materials brought by the festival.

Table 29: Spreadsheet configuration of SORT.

Reuse scenario	
Sheet name	*Content*
Parameters	Parameters of the waste management system in Catalonia, including cross-contamination levels, destination of rest, emission factors, and water use.
newData	List of inputs of BAU and of the new system, including the new materials backstage (in pink).
MFAreu	Material Flow Analysis calculations. It includes the list of inputs from the festival, estimated inputs from the attendees, collected waste, and estimated recycling levels and losses. The flows of materials avoided with the package-free store are detailed as well. To change between variations, the yellow cell must be set to: • Nothing → BAU • "A" or "a" → variation A • "B" or "b" → variation B • "C" or "c" → variation C • "D" or "d" → variation D • "E" or "e" → variation E
ZWI	Zero Waste Index calculations for all the variations. In this sheet there are also the values of how much of the waste collected, recycled, and lost was under the responsibility of the festival.
CF	Carbon Footprint calculations. It includes the list of inputs from the festival and their emission factors, and of the products avoided with the store.
WF	Water Footprint calculations. It includes the list of inputs from the festival and their water use factors, and of the products avoided with the store. The water footprint is only calculated for the materials brought by the festival, but the avoided products are deducted from the total.

Table 30: Spreadsheet configuration of REU.

Ideal scenario

Sheet name	*Content*
Parameters	Parameters of the waste management system in Catalonia, including cross-contamination levels, destination of rest, emission factors, and water use.
newData	List of inputs of BAU and of the new system, including the new materials backstage (in pink) and in the plastic-free store (in blue).
MFAideal	Material Flow Analysis calculations. It includes the list of inputs from the festival, estimated inputs from the attendees, collected waste, and estimated recycling levels and losses. The flows of materials avoided with the plastic-free store are detailed as well. To change between variations, the yellow cell must be set to: • Nothing → BAU • Any number or letter → IDEAL
ZWI	Zero Waste Index calculations of BAU and IDEAL. In this sheet there are also the values of how much of the waste collected, recycled, and lost was under the responsibility of the festival.
CF	Carbon Footprint calculations. It includes the list of inputs from the festival and their emission factors, and of the products avoided with the store.
WF	Water Footprint calculations. It includes the list of inputs from the festival and their water use factors, and of the products avoided with the store. The water footprint is only calculated for the materials brought by the festival, but the avoided products are deducted from the total.

Table 31: Spreadsheet configuration of IDEAL.