urban science

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Exploring and Illustrating the (Inter-)Disciplinarity of Waste and Zero Waste Management

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Received: 2 October 2020; Accepted: 26 November 2020; Published: 8 December 2020

Abstract: The aim of this research was to explore the composition, contribution and arrangement of scientific disciplines, across the spectrum from, traditional waste management, to alternative, contemporary approaches, such as the zero waste and circular economy movements. The purpose of this research is to better address the challenge of waste by enhancing the understanding and future employment of interdisciplinary theory and practice. The first outcome of the review strategy employed in this research was to, illustrate a generic rubric of scientific disciplines and to highlight and discuss key disciplines most obviously connected to waste management. This graphic illustration was then overlain with the findings from systematically reviewing a diverse range of indicators and sources of insight and information on the disciplines and interdisciplinarity evident across the spectrum from waste to zero waste management approaches. The resulting final graphic illustrates the intense disciplinarity and hence, the significant interdisciplinary requirement of (zero) waste management. An observation emerging from this research is that, successfully managing the globalised complexity of waste issues and in this, addressing the challenges of climate change and sustainable development, requires cultivating synergy between multiple scientific and practical disciplines. The scope of this challenge increases with the adoption of more holistic, aspirational, countercultural approaches, such as zero waste. It is argued that, enhancing interdisciplinary training and collaboration in research, education and industry/community practice, will improve performance across the spectrum of worldviews, from waste to zero waste.

Keywords: waste management; disciplines; interdisciplinary; zero waste; circular economy

1. Introduction: Waste → Zero Waste Management

The imperative of addressing big research questions and critical real-world problems [aka "war, crisis and need" [1], is reported as having been a conceptual driver of interdisciplinarity in the first half of the 20th century [2,3]. Citing the consilience and interdisciplinary collaboration, which lead to *cracking* the DNA code, Rhoten [4] argues that, the big opportunity of "cross boundary science" is to realise the potential for revolutionary breakthrough. The association with breakthrough success, combined with increasing awareness around acute global issues, has led to interdisciplinarity being cited as a contemporary "mantra" in research [5]. The theory and practice of interdisciplinary education and research, is part of a far-reaching societal paradigm shift and is now both, an essential "fixture of the modern academy" [3] and an established focus of research funding processes [6]. Strengthening knowledge and experience of interdisciplinary practice, is conceived as a powerful new opportunity for generating breakthroughs in response to critical global imperatives.

Waste can be recognised as amongst the most challenging and complex anthropogenic problems being faced globally [7,8]. The International Solid Waste association (ISWA) uses the term "global health emergency" and in response calls for "emergency programmes" to address the most acute aspects of this challenge [9]. The resource exploitation, linearity, toxicity, leakage, loss of material

value inherent to waste disposal, alongside what social and environmental costs are ignored and externalised from this model, combine to make waste issues wickedly complex [10,11]. Contingent with the scale and acuity of these systematic issues, achieving genuinely sustainable management of waste, is both a critically important sphere of human activity and is one which requires a transformational level of breakthrough and progress [12].

Waste should be regarded as, as much a consideration of *social science*, as it is a technological concern, needing a 'science, technology, engineering, mathematics'(*aka, STEM*) derived fix. This *social* basis can be recognised within formal definitions of waste, where the selected, declared material identity of *waste* (i.e., vs. the status of being considered a resource) is simply a *value judgement*, based upon variable human conception [13,14]. The preeminent social science/humanities basis for addressing waste, is also reflected in the location of reduce, as the top priority of the waste hierarchy, which provides a ubiquitous (albeit varying and contested) policy theorem, across waste management. Identifying reduce as the top priority, ahead of all other elements of the waste hierarchy, emphasises the criticality of socialised community values, behaviour and choice. However, in reality this notional priority, is seldom reflected in the physical praxis of the waste management industry [8,15], which remains heavily vested at the bottom of the waste hierarchy and by activity, toward the traditional default of disposal [16,17].

In a wide review of assessment methods for solid waste management, the comparative analysis of the *objects of investigation* undertaken by Allesch and Brunner [18] established that, only 4% of studies were focused on the top two priorities of the waste hierarchy, i.e., reduction and reuse. The indications are that, the top two practices prioritised in the waste hierarchy, are omitted, misunderstood, difficult and or, apparently unpopular research practices. This *rhetoric* vs. *reality* gap, presents as a theoretical tension within policy discourse around waste and points to a dissonance in the comprehension of and relationship between, the historic disciplinary foundations of waste management and the transformational future requirement in respect of natural resource conservation, sustainable development and climate change [19–21]. The embedded societal default setting towards disposal, rather than reduction (i.e., to the bottom, rather than the top priority of the waste hierarchy), indicates the dominance of a traditional disciplinary worldview-aka "disciplinary chauvinism" [22] within waste management practice.

Coinciding with questions arising around the problems and lack of progress attributed to traditional/conventional waste management, numerous positive indicators are now emerging from anecdotal and scientific, reporting of individual, family/household and community zero waste practice [23–30]. Whilst quantifying and qualifying the comparative performance of waste vs. zero waste management approaches, certainly deserves more formal scientific attention [31], these positive indicators, serves to challenge the historical assumptions and the fiscal, practical, theoretical and disciplinary conventions of the traditional waste management sector [32]. Today, an accumulating body of zero waste literature and experience confirm the achievability of priorities at the top of the waste hierarchy [31,33]. Simple, cost effective individual/community-based behavioural change, renewed strategy/policy/design frameworks and allied investment in appropriate technology, infrastructure and services, can significantly reduce and address *end of pipe* waste (i.e., at source—pre-generation—pre-discard—pre-disposal), before it manifests as a problem.

Zero waste can be conceptualised as the antithesis of the socio-economic design construct, commonly known as the *throwaway society*, which is founded in the false premise of inexhaustible natural resources and infinite, consequence free disposability [34]. The acute fallacy and environmental illiteracy, dysfunction and consequence of this lineal socio-economic model, is now gravely exposed in accumulating scientific evidence [35]. However, despite numerous and stark citations of alarm (i.e., e*cological meltdown* [36], *war against nature, Gaia killers* [37,38], *industrialism—cancer* [39], *Growth fetish, Affluenza* [40,41], *unprecedented emergency* [42], *suicide machine* [43], *climate catastrophe* [44], *Collapse* [45]), this flawed socialisation, has been compounded by decades of advertising and lobbying, which has normalised consumerism, political acquiesce and policy capture by vested interests [46,47].

The "take – make-waste/dispose" lineal economic model, derivative of this socialisation [48,49] has, from inception been willingly synchronised to the "flame, flush and fling" disposal reflex [50], which mechanise the corequisites of convenience and (albeit illusory) disappearance.

At one level, the symptoms of the global waste crisis are stark, unsightly and self-evident, however, much of the true environmental cost and consequence is obscured, slow to manifest, externalised and under-reported (i.e., greenhouse gas emissions (GHG) and other harmful pollutants [51]. Today, it appears broadly accepted that the pollution, toxicity and environmental degradation inherent to this linear, disposal-based socio-economic model, is neither sensible, or sustainable [32]. Further, it can be argued that, the accelerating accumulation of environmental impacts, now subverts the originally noble intent and overall benefit of capitalism [52,53] and consequently for some, *crapitalism* is the resulting derogation [54–57]. However, whilst consensus may be said to be converging around issue, the mechanics, brand and trajectory of our, *where to from here* response, continues to provoke considerable and varied debate.

The realisation of the necessity for change, now appears within discourse around traditional, disposal orientated waste management theory and practice [58]. For example, the historic framing of "linear Integrated Waste Management Systems (IWMSs)", is now cited as evolving into, "circular IWMSs (CIWMSs)" [11]. In concert with conventional waste industry praxis being re-conceptualised, reformatted and re-languaged, a progressive symmetry is discernible across the spectrum of alterative waste management movements, cited as responding to the crisis of waste [32,59].

Whilst, pioneering commercially orientated and various national, state/regional, town/city zero waste and circular economy initiatives, can be regarded as recent *development drivers* of more sustainable urban waste management systems, it is equally important to recognise other contributors in this progression. For example, innovative German, French and subsequent Japanese and Korean packaging laws, are cited as being instrumental in the modern recycling movement, as well as inspirational demonstrations of product stewardship/producer responsibility [60–62]. Progress is formed via many contributing strands, which each serve to build community awareness, engagement and innovation in the design and development of more sustainable urban waste management systems and more circular economic metabolism, which combine in addressing climate change [32,63].

These progressive movements, can be viewed as part of dynamic milieu of sustainability ideas/ideals, rhetoric, and activity [64,65], which coincide in interpreting waste as a resource and opportunity, rather than just a problem [66]. Such *post-waste* movements [67] recognise the positive: energy, water, GHG emission, chemical pollution, socio-cultural and economic implications, in respect of conserving and cycling resource flows, mitigating climate change and transitioning into more sustainable development [12,68–70].

This emerging cluster of sustainable waste (aka resource) management movements, include several overlapping intellectual disciplines and associated spheres of theory and practice, which can all be variously interpreted responding to waste, as both an acute global environmental crisis [9] and physical emblem of broad systemic failure [71]. The milieu of respondents includes: zero waste (ZW), zero emissions (ZE), circular economy (CE), industrial ecology/symbiosis (IES), urban metabolism (UM) and bioeconomy (BE), which all identify in the commonality of seeking to actualise the *ecosystem metaphor* of infinite-perpetual resource life-cycles and naturalistic design principles [72–76].

Aside from fundamentally rejecting the socialisation of waste [46], this genre of highly aspirational, future-focussed movements, align in seeking to disrupt and replace routine environmental exploitation, disposal and externalised pollution costs, with the polar opposites. Namely, normalised maximum material: resource conservation, stewardship/responsibility, efficiency and circularity [77]. An essential platform for engineering this transformation is the design and deployment of market-based economic instruments and incentives and regulatory interventions, which enact genuine producer–consumer responsibility [78] and empower regenerative re-design, dematerialising, detoxing, circularising and upcycling all resource flows within economy [79].

The largely unexamined, unaccounted, true cost of waste, eludes the majority of our economic calculus and is still not fully or accurately factored into market pricing, through comprehensive and effective policy instruments, such as Extended Producer Responsibility (EPR)/Product Stewardship (PS) systems [11,78]. This genre of policy platforms confront traditional waste management's limited *end of pipe* focus and in essence, permanently re-orientates waste management theory into a *big picture* mode, attuned to holistic, integrated systems thinking, ecological economics and socio-cultural imperatives [75,80,81]. In future, efforts seeking to address the issue of waste, need to be applied at every stage, from inception in design, production, product and packaging systems and from the point of natural resource extraction, refining, transport, manufacturing, sale-purchase, use phase, as well as to *end of life* utility and eventual disposal [49,82].

Whilst, much positive change is being catalysed, currently, linearity and wastefulness still typifies most industry sectors', supply chains and product types [17]. The result is that the fate of most material resources flowing through the global economy remain preordained for disposal [83]. This systemic socio-economic design failure appears so entrenched in our *anthropogenic DNA* [84] that, despite billions of dollars invested over+40 years to actualise the priorities expressed in the waste hierarchy, genuinely transformational change, remains elusive [32]. However, despite the apparent barriers and inertia, projected savings of up to a 5-10 times the implementation cost and numerous gains on the *United Nations Sustainable Development Goals* are projected, are claimed for proactive investment targeting the most acute global waste issues [85]. Such projections reinforce and amplify the case for aspirational goal setting and a continuum assertive action-plans, including the deployment of proven market based policy instruments/incentives, regulatory interventions and requisite new services, infrastructure and technologies [86].

Whilst commonality exists amongst the emerging, *green/sustainable* genre of (zero) waste management movements, so to does debate and controversy [87]. In particular, whilst the zero waste, attracts affirmation and support, the movement can also be a lightning rod for criticism [88]. Arguably, within this *green/sustainable* genre, zero waste is the most extreme and controversial variant [32]. Zero waste embraces: activism (i.e., confronting both the fundamental concept of waste and the vested commercial interests, which make, manage and profit from waste), hyper-aspirational terminology, a transgressive ideal and continuum of innovation and, elevating the role and responsibility of community, ahead of private sector/professionalised industry control over change-making processes [33,89,90]. Zero waste appears to attract a polarised characterisation, i.e., on one hand, as a chronic failure and doomed on the basis of a non-existent, un-implementable blueprint/methodology [91–93] and in contrast, as a successful, scientific and popular catalyst of a *2nd—green industrial revolution*, [81,94].

Arguably, such polarisation relates to zero waste embracing extremity and confrontation, inclusion and heterogeneity and the attendant complexity, contradictions and confusion which result. At least, as is obviated in terminology, zero waste seeks to project as being both, the antithesis of waste and at the zenith of prospecting solutions to expedite change, commensurate with the "super-wicked" problematicity of waste [95,96]. However, controversy and debate, is not just confined to zero waste and arguably typifies this dynamic sphere of scientific discourse. For example, whilst it can be generally accepted that "the world can't recycle its way out of waste" [97], recycling is labelled both, the "most successful environmental initiative in human history" [98] and maintains a strong scientific value proposition [99]. Speaking to the hyper connectivity and interrelatedness of waste, Humes [100] observes that, waste connects to "everything: energy, food, pollution, water, health, politics, climate, economics".

This connectivity and complexity relates to the fact that, since antiquity, *managing* the issue and opportunity of waste has involved contested and overlapping theorem, terminology, commercial interests, materiality, ownership and merged intellectual formation and histories, etc. For example, from the outset, the chronicles of archaic resource recovery/recycling practices (i.e., Chinese composting/European Bronze age scrap metal systems) appears intertwined with those of disposal

(i.e., Greek landfills and associated decrees) in the formation of what, latterly emerges as *industries* for managing wastes/recovering resources [101]. This interrelationship is reinforced in histographies, which in identifying terms, such as *Rag–n–Bone men, Toshers, Mud-larks, Rakers and Dustmen*, arguably denote the first composite of disciplinary indicators for waste management [16,102]. Other historical records, i.e., *The Association of Cleansing Superintendents*, in encouraging members to deal with waste: "rapidly, scientifically and hygienically and very often so as to create a commercial commodity" [103], serve to reinforce the mutuality of treating/exiting issue, with identifying and extracting value [16]. Such accounts also offer insight to the disciplinary formation of waste (and latterly zero waste) management and the composition and synthesis, which involves motive, objective, function, locus, context, activity, process, materiality, economics, socialisation, status, edict and censure, etc. [46,104,105].

This article acknowledges the extremity of zero waste, within the dynamic spectrum of sustainability movements/disciplines (i.e., ZW, ZE, CE, IES, UM, BE and CIWMs etc.) focused on deriving new and transformational ways of addressing the issues and opportunity associated with waste. This genre of activity can be conceptualised as a *change-making* transitional spectrum and abbreviated/annotated via the encompassing extremities of: *waste* → *zero* waste, aka (zero) waste management. In this article this abbreviation is used without prejudice, or exclusion to any of the movements/brands operating in the sustainable waste/resource management space. It is recognised that, a multiplicity of efforts is pioneering innovation, research and development, progressive and successful case studies. At this point, it is not yet known what individual, or combination of initiatives may catalyse the requisite transformational breakthroughs, which will usher in the envisioned new era of sustainable waste/resource management. Therefore, there is inherent value in both maintaining a *biodiversity* of responses, prospecting a range of potential solutions and in cultivating an urgent continuum of experimentation around all opportunities for generating progress [32].

A question common to this sphere of activity is then: what will reverse perceptions of failure and dysfunction associated with the global crisis of waste and what will enable the envisioned transition from issue to opportunity? The research supporting this article explores how the concept of failure vs success, which is debated in respect of the *waste* → *zero waste* transition spectrum, can be interpreted and explored within a wider realisation of the shortcomings of traditional disciplinary thinking and practice. It can be argued that this omission is compounded by inadequate understanding of the complex (inter) disciplinarity of (zero) waste management. Moreover, it can be argued that the cited *super wickedness* of the globalised waste crisis, necessitates an urgent advancing of interdisciplinarity comprehension, training and collaboration across the spectrum of waste → zero waste related research, education and industry practice.

Literature supports the view that, a baseline of interdisciplinary skill and experience, provides a necessary foundation for the kind of transgressive, transformational, transdisciplinary breakthroughs [2,22], which appear as a common aspiration across the *waste* → *zero waste* transition spectrum, but which are yet to be fully explored, or realised [32,50]. This research aimed to complete a diverse and detailed examination of sources of information and insight into the composition and contribution of disciplines and interdisciplinarity across the spectrum from, traditional waste management, to the emerging alternative, contemporary approaches, offered by for example the zero waste and circular economy movements. It follows that the purpose of this research is to contribute to the opportunity of enhancing the (zero) waste management sector's understanding and future employment of interdisciplinary theory and practice, in addresses the acute challenge of waste.

2. Background: Disciplines and Interdisciplinarity in the Context of Waste

Historically, disciplinary excess (aka *chauvinism*) has been associated with over-reaching "truth claims", reductionist pretence [2], the questionable proposition of singular final solutions, even denial/delay of scientific consensus and delimited progress in overcoming wicked issues [106,107]. The phenomena of interdisciplinarity is part of the *where to from here*, as the limitations of overly rigid disciplines were realised and then deliberately disrupted [3]. Initially grounded in the university setting

and assisted by the radicalising currents of the 1960's, the interdisciplinary imperative progressed along two interrelated development pathways, namely research and education. The movement for interdisciplinary studies can be interpreted as, both a reaction to an accumulating fragmentation of knowledge and the then, dominant disciplines' failure to explicate the great social movements (i.e., human, civil and women's rights and the ideological *anti-* struggles against war, racism and imperialism) [3].

The emergence of new intellectual fields (such as African-American, woman's, ethnic and development studies), alongside pioneering interdisciplinarians questioning what constitutes legitimate subjects, processes of learning and enquiry [108], can be interpreted as a deliberate and necessary circumvention of disciplinary convention and authority [3]. The ascent of zero waste (and the other alternative neologism, such the circular economy movement) colonising and competing in the sphere, traditionally dominated by conventional waste management theory and practice, represents a similar questioning of, theoretical convention. Movements/initiatives across the *waste* → *zero waste* transitional spectrum, challenge the limited *end of pipe* industry foci, and confront vested interest complicity in the environmental issues stemming from the current, lineal socio-economic model premised on *making and managing* waste [32].

Interdisciplinarity is described as having become a major topic in academic policy, in the post 1960's discourse around knowledge production structures [109]. Reflecting this ascendance, interdisciplinary science has been identified as a catalyst for reshaping the way U.S. Doctoral programmes became conceived of, as formative of future socio-economic development [110]. Reflecting the recognised importance of interdisciplinary research in U.S. universities, a repertoire of organisational arrangements, financial incentives, recruitment and evaluation models are described as being employed at all institutional levels and between departments and disciplines [6].

Today interdisciplinarity appears as an intellectual megatrend, powered by an accumulation of globalised, historic, evolutionary, cultural and socio-economic forces [111]. Scientific, technological and social *progress to date*, as well as the plethora of issues and opportunities that emerge with this, can be seen as having exposed a, void space in our ability to understand and bridge rapid change and exponential complexity. Bridging this void, called for cognitive processes beyond the perceived limitations of traditional disciplinary silos and provokes the exceeding, deconstruction and recombination of traditional disciplines [111].

Another contemporary impetus for interdisciplinarity is cited as a socialised realisation of the inherent complexity of *nature and society* and as a result, conception of problems and questions, beyond the scope of any single discipline, which frames a demand for solutions, based upon revolutionary insight and regenerative technologies [3]. However, a fundamental driver of interdisciplinarity, is also said to originate from within the, post-modern conception of the *individual* and the recognition of: multiple intellectual curiosities and interests, a spectrum of skills and abilities and an often divergent plurality of career fields and life experiences, which exceed outdated and overly rigid and disciplinary perspectives [112].

Increasingly, across fields as diverse as health and social science, business, education, policy/management and the *sustainability sciences*, where human and bio-physical systems interface, it is recognisable that real-world complexity, encourages the *boundary work* of deconstructing any barriers and limitations arising from rigid conventional disciplinarity [22,113]. However, whilst the sustainability sciences have grown into a formidable field of problem-driven, interdisciplinary scholarship, this can be critiqued around the "blind spot" of, not routinely exhibiting explicit and justified systematic procedures for conducting interdisciplinary research [114].

Alongside a required procedural basis, interdisciplinarity is premised upon an assumption of *reality beyond academy* and reliance upon, transgressing and transcending redundant convention and discipline [2,3]. Alongside being an iteration in attempts to address the pathologies attributable to *anthropogenic progress*, interdisciplinarity can also be catholically interpreted as, a functional necessity

for reshaping both, how humanity thinks, enables and catalyses *big transitions* [3], i.e., beyond current inertia in addressing climate change and sustainable development.

The inextricable value and yet failure of discipline, is foundational to the circumventive tools inherent to interdisciplinarity, such as "cognitive decentring" [3]. This is described as, the intellectual ability to shift consideration around a "variety of perspectives and in this to perceive reality more accurately, process information more systematically and solve problems more effectively" [3]. Repko also argues that, the innate *cognitive stretch* of interdisciplinarity, systematically fosters new and critical intellectual abilities, structural knowledge and multiple character traits and skills [3]. This propensity for merging *IQ and EQ*, appears critical to education and research in transitional spheres (i.e., involving disruption, revision and reassembly) such as between, the cited extremities of worldview, between traditional waste (management) and zero waste (elimination). Enhancing understanding of and normalising interdisciplinary education and research practice, appears critical to navigating the exponential lift in aspiration, challenge and complexity *(aka everythingness)* requisite to paradigm shifts, such as from waste → zero waste.

Whilst seemingly a contradiction, it is important to observe that interdisciplinarity discourse recognises and values traditional disciplines and the contribution these make to the development of scientific method (i.e., in the form of shared frames of reference, language, theoretical canon and peer recognition, which enhances epistemological and ontological rigor) and the progression of knowledge [22]. One of the critical assumptions anchoring interdisciplinarity is that, disciplines are seen as essential foundations, rather than entirely rejected by most interdisciplinarians. Interdisciplinary education and research can be seen as both, anchored in disciplines and as, corrective of their unhelpful dominance and limitation in addressing the expansive complexity of reality, beyond what can be fully appraised and functionally contained in academia [3].

This attribute of mutable plurality, is of particular interest and analogy to this research context which examines (inter)disciplinarity in respect of the concept of a transitional *waste → zero waste* spectrum of activity. For example, in challenging and to a degree rejecting the tenets of traditional waste management, the concept of zero waste (i.e., as reflected in the alternative zero waste hierarchy) can interpreted as maximally assertive of some key waste management fundamentals (i.e., the 3Rs: reduce, reuse and recycle), whilst notionally rejecting others. However, whilst outwardly confronting and rejecting disposal, all zero waste programmes are tacitly dependant on this, as an interim function, whilst working to supplant this dependency by investing in a systematic continuum of ideal, innovation and infrastructural transformation [89,115].

Illustrating the *inter-ness* attribute of interdisciplinarity, Aboelela et al., offers the following multi-sector definition of interdisciplinary research:

> " . . . studies undertaken by scholars from two or more distinct scientific disciplines . . . based upon a conceptual model that links or integrates theoretical frameworks from those disciplines, uses study design and methodology that is not limited to any one field, and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process" [112].

As such, interdisciplinary research, in typically addressing real-world problems/challenges, can be seen as inviting participants from, often diverse scientific backgrounds, to cooperatively cross boundaries and bridge disciplinary perspective in the creation of new knowledge [22]. In seeking to advance prior levels of integration, interdisciplinarity draws out a higher degree of literacy around both the basic philosophy of science and across the participating disciplines.

In practice, interdisciplinary research has been variously characterised as, *unidirectional*, where one discipline leads or controls integrative process and alternatively as, *goal-orientated* where issue-centricity guides the project [22]. Additionally, interdisciplinary research can be described as "big", where otherwise distant disciplines are bridged [for example, the erstwhile divergent paradigms of natural and human sciences as discussed by [112], as well as conversely "small", where

more closely related (or isolated sub-) disciplines are engaged [22]. Analogous to the *big–small* categorisation of interdisciplinarity, Stock and Burton [22] also identify and extend discussion around *weak*, i.e., relying on traditional methods and logic [116] vs. *strong* transdisciplinarity, which recognises simultaneous models of reasoning, rationale and non-linear relationships.

On this basis, it appears the multiple characterisations can be argued for the *waste* → *zero waste* transition context. These perspective on interdisciplinarity, appears particularly relevant to the assertion that, in reality, waste is as much a social consideration, as it is a technical/engineering science and challenge. However, it has also been argued that the recognised diversity and inherent complexity of interdisciplinary research "defies a single definition" [109]. It appears that the pragmatic and useful concept of a *spectrum of disciplinary integration* has arisen out the academy wrestling for greater clarity and definition across the interdisciplinary movement. Coining the term "MIT disciplinarity", Stock and Burton [22] orientate interdisciplinarity between multi- and trans- on their *spectrum of disciplinary integration*.

In respect of the historical development of *integrated waste management* (IWM) as a theroetical model, Seadon reports [117] this as a progression beyond the initial foundational basis in the waste hierarchy, prompted by consideration of both, "direct impacts (transportation, collection, treatment and disposal of waste) and indirect impacts (use of waste materials and energy outside the waste management system)". The authors view is that, the initially compartmentalised IWM thinking, latterly evolved toward a more interconnected soft systems approach, capable of incorporating and optimising existing, with new programme developments and encompassing all physical dimensions (solid, liquid and gas) of waste [50].

Alongside recognising the progression into and the importance and detail of *sustainable* waste management systems (WMS) Seadon [50] aligns and discusses how an evolving *transitional spectrum* of approaches to waste management can be related to an advancing scale of disciplinary integration. The author's observation is that, in more advanced/sustainable WMS thinking, problems are conceived as being multidimensional (i.e., including environmental, socio- economic) and multidisciplinary and as a result, solution seeking interventions (and the analysis by which these are developed) needs to reflect these real-world complexities [50,117]. In profiling and relating this spectrum of disciplinary integration to evolving waste management theorem, the inference is that, depending in how waste management systems and thinking is conceived and or, has evolved, all can be interpreted and located along this spectrum from, singular disciplinarity → highly integrated transdisciplinarity [50] (Table 1 below).

Table 1. A spectrum of disciplinary integration related to evolution in waste management theory. Source [50]. This outlines how evolution and advancement in waste management (including more environmentally and socially sustainable options) approaches can be related to an advancing scale of disciplinary integration.

Disciplinarity	Multi-Disciplinarity	Pluri-Disciplinarity	Inter-Disciplinarity	Trans-Disciplinarity
Reductionist: Splitting into separate waste streams for management	Reductionist: Consider different waste without links	Cooperation but no coordination between waste stream management	Waste stream management coordination from a higher level	Systems: Coordination of management between all levels and all waste streams

However the integrative spectrum is delineated and described, fundamentally the integrative, *beyond disciplines* movement, involves an inherent questioning of: dominant axiom, reductionism, mechanistic assumption and breaching the accumulating hegemony around the praxis and cannon of traditional disciplines [22]. Sometimes described as the "holy grail" of disciplinary integration, transdisciplinarity is located and described at what is clearly the highly aspirational, yet to be fully realised end of the MIT integrative spectrum [22]. This appears to align with the characteristics of disruption, transgression and hyper-aspirational continuum, attributed, to zero waste and the cluster

of alterative sustainable waste management brands and movements, which conceptually reject waste and occupy the futurist conception of *other, next and beyond* [12].

The background to the research reported in this article, is the escalating global concern about waste as an acute environmental issue. Associated with this concern, is debate around the performance of traditional waste management practices, vs. the spectrum of alterative, sustainability focused approaches to this problem, i.e., the circular economy and zero waste movements. The aim and purpose of this research encompass a series of linked questions, which arise in this debate. For example, what mix of scientific/practical disciplines are required in compiling a more effective approach to (zero) waste management? A related imperative for industry and government leaders globally is, how can the performance and outcomes of (zero) waste management policies, programmes and services, be exponentially improved, so as to achieve the numerous and commonly cited, aspirational goals?

Further, given the significant complexity and barriers to progress apparent in this sphere, should waste management (and even more so, the hyper aspirational alternative approach of zero waste management), be considered multi-disciplinary spheres of activity, requiring highly interdisciplinary (if not transdisciplinary) comprehension and practice? If this is the case, it follows that, potentially a lack normative interdisciplinary comprehension, training/skills and practice amongst (zero) waste managers, may be part of the problem in addressing the globalised waste crisis. The research underwriting this article sought to explore such questions and to better understand the relationship between disciplines, aka the interdisciplinarity across the spectrum of activity from traditional waste, to zero waste management perspectives.

3. Methodology

3.1. Visualising a Generic Disciplinary Framework for Science

The first stage of exploring the disciplinarity of conventional waste management was to compile a baseline general scientific disciplinary framework. Figure 1 provides a graphic illustration of this generic framework of *scientific disciplines*. This was developed as a compilation/interpretation of two sources: 1- the taxonomy of disciplines, based on the National Science Foundation (NSF) longitudinal survey of doctorate recipients and 2- the National Commission for Scientific and Technological Research (CONICYT)/Organisation for Economic Cooperation and Development (OECD) list of disciplines. This formation was then examined relative to other relevant academic literature and the evolving open source consensus around *branches of science*, expressed in the Wikipedia platform. By way of comparison and confirmation, this generalised disciplinary framework coincides with, but expands on, the general tabular categorisation of disciplines reported by Repko and Szostak [118]. The expansions recognised and encompassed in Figure 1 are: the inclusion and demarcation of *Applied, Interdisciplinary* and *Formal* sciences, the allocation of mathematics under the *Formal Science* category and the separation of *Life* and *Physical* sciences under the classification of *Natural Science*. However, the Figure 1 framework model also incorporates variations. For example, whilst Repko & Szostak classify *Social Sciences* (SS) as separate from *Humanities* (H), in Figure 1 (and thereafter) these are identified as demarcations under a combined (i.e., SS & H) classification.

Figure 1. A compilation and arrangement of scientific disciplines illustrating a commonly recognised connection to (zero) waste management, highlighted in yellow.

Notably, all of the sixteen main named disciplines outlined and subsequently explored by Repko & Szostak are identifiable in the Figure 1 framework, alongside an initial sixty-three others, including the identification of twenty-three *Interdisciplinary Science* disciplines (NB: many other sub-disciplines or sub-fields are also identified). The only key departure between the Figure 1 framing and that offered by Repko & Szostak, relates to mathematics. The consensus position illustrated in Figure 1, identifies mathematics as a *Formal*, rather than a *Natural Science*. The selection of the illustrative rubric of overlapping bubbles, used in Figure 1 is supported by Repko & Szostak's [118] perspective that, interdisciplinarians should approach disciplines, not as rigidly self-contained repositories of information, but as open frameworks with a wide range of concepts methods theories and methods, which transcend traditional boundaries.

This graphic illustration of a generic scientific disciplinary framework, in this instance with the association with conventional waste management highlighted (i.e., yellow highlights in Figure 1) provides a baseline context for, exploring how other spheres of knowledge and practice, related to and requisite across the full waste → zero waste transitional spectrum, might interface with this rubric. The disciplines/subject areas highlighted in yellow in Figure 1, provides an initial indicative overview of commonly recognisable connections/contributions to waste management and recycling. These indicative highlights are based on observations emerging from the literature review combined with applying the precedent of interpretation based on background industry knowledge and professional educational and research related experience [119,120].

Notably, because the term *waste management* was not specifically identified as a scientific discipline/field in any of the source documents, this specific term was not compiled into the initial Figure 1 framework. The nearest, indirect reference to *waste management* appears to be the inclusion of *sustainability/sustainable development*, as a demarcation within the interdisciplinary sciences. Based on the identification of *waste minimisation* and *zero waste* within a defined sustainability framework [64], and broad industry recognition of the key role waste management plays within sustainable development [85,121], this appears as a justifiable point of identification and location within the generic Figure 1 disciplinary framework. However, overall, the analysis offered in the process of forming Figure 1, highlights a sense of omission and lack of clarity around how the concept of a transitional *waste* → *zero waste* management spectrum, interfaces with the disciplinary rubric of science. The next sections of this article seek to address this and to further explore and explicate the disciplines and interdisciplinarity of (zero) waste management.

3.2. Exploring the Disciplines and Interdisciplinarity of Waste and Zero Waste Management

Figure 1 provided both a baseline framework of scientific disciplines and then highlights commonly recognisable linkages to conventional waste management (i.e., inc. recycling, etc.). The next step was to design a more formal systematic search—review strategy (illustrated as Figure 2 below) to further explore the disciplines and interdisciplinarity across the evolving spectrum from waste →zero waste management. Seven interrelated (inter)disciplinary indictors were selected and examined as key opportunities to provide insight and better understanding the (inter)disciplinarity of (zero) waste management (ref. the following Sections 3.3–3.9). The design and implementation of this review strategy, enabled the prior generic framework of scientific disciplines (with commonly recognisable waste management connections highlighted), to be overlain and reorganised on the basis of the additional information and insights to the (inter)disciplinarity of (zero) waste management. The compilation and illustration of key findings are subsequently presented in the *Results* section.

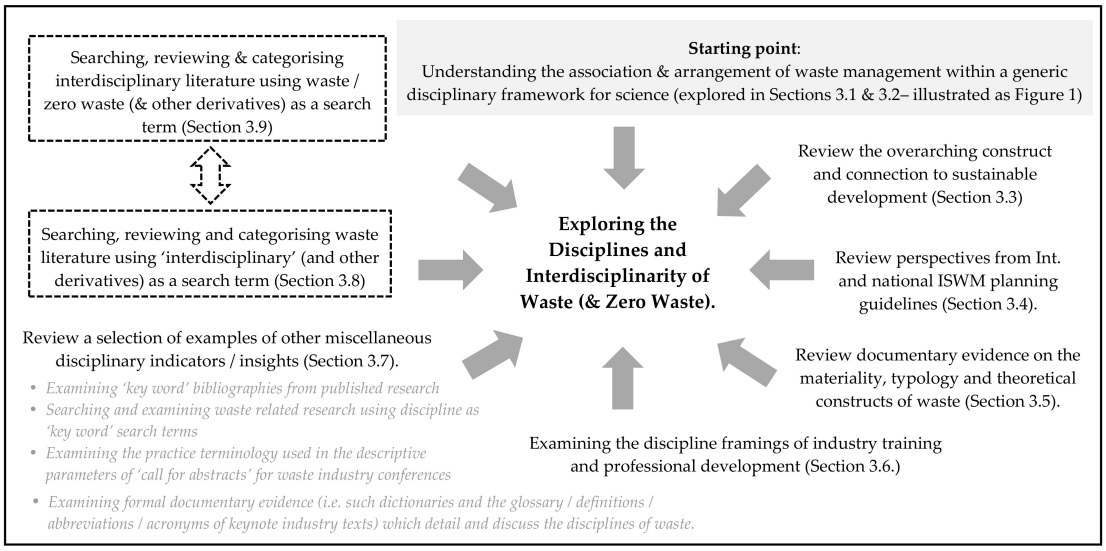

Figure 2. An explorative review model designed to provide insight into the (inter)disciplinarity of (zero) waste management. This illustrates the seven interrelated perspectives, which formed as a search strategy to identify and review sources of indicative terminology, references and perspectives on the disciplinarity of waste (and zero waste) management. It can be recognised that a variety of alternative inclusions and or approaches may also provide an equally viable systematic review/search model. However, in practice this grouping proved effective and produced an extensive data set.

The implementation of the systematic search-review strategy illustrated as Figure 2 (above) resulted in securing a range of credible source documents, which provided a range of descriptors of: the spectrum of types, sources and definitions of waste, necessary stakeholders, treatment processes/technologies, emerging concepts of ownership, stewardship and control of the handling and logistics chain [122] of waste/material resource flows, alongside the relevant skills and training required in this field. Collectively, these individual insights combined to form a multi-focal perspective on the (inter)disciplinarity of waste and zero waste management approaches. The following Sections 3.3–3.9 provides a brief explanation and discussion of each of the individual elements of the systematic search/review strategy illustrated as Figure 2 (above).

3.3. Disciplinary Indicators from Examining the Waste Connection to Sustainable Development

Graphic illustrations offered by a variety of publications were identified, which each contributed useful perspectives on the disciplinary associations around waste management. For example, Glavic & Lukman developed a three-dimensional visualisation of sustainability orientated terms and definitions (ref. full glossary Figure 3). The authors formally categorise and co-locate waste minimisation and zero waste as *approaches* (on the same level as: *cleaner production*, *eco-design* and *life cycle assessment)*, orientated one level above and toward *society* and *environment* (versus *economy*), as two of the three foundational principles, within a sustainable development hierarchy [64]. This integrated picture, whereby waste/resources focused spheres of activity, such as ZW, ZE, CE, IES, UM, BE and CIWMs are immersed into the broader sustainability/sustainable development movement, appears numerously support by early and latter commentators [31,75,123,124].

Another graphic illustration which explores the high level relationship between waste and sustainability/sustainable development included, the United Nations Environment Program's (UNEP) *General concepts related to sound waste management* [89]. This conceptual model offered by the UNEP, echoes the structural arrangement, connection and alignment, whereby forms/expressions of waste management are imbedded and oriented in potential synergy with the multitude spheres, interrelated professional fields and or intellectual disciplines of sustainability/sustainable development [89]. Significantly, given the New Zealand context of this research, the broad tenet of these types conceptual

models was confirmed in the inclusion and examination of a local, real-world programme example, illustrating intense (vertical and horizontal) integration in seeking to generate "sustainable waste management" systems at an industrial scale [50], i.e., the New Zealand, Fonterra Dairy Cooperative.

3.4. Disciplinarity Indicators from National Waste Management Planning Guidelines

Selected examples of formal national and international, waste management planning documents, offer further insight into the disciplinarity of waste. Table A1: included as Appendix A, outlines the compilation and interpretation of information sourced collectively from the: Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities and the Developing Integrated Solid Waste Plan: ISWM Plan—Training Manuals Volume 1- 4, documents developed by [89,125]. This data illustrates the elements and guidance, which the UNEP identified as essential for managing waste and the operative statements, practice related verbs, roles and capacity terms, which provide insight into what the waste management sector pragmatically does. As such, the findings synthesised in Table A1, provides numerous, multilevel indicators as to the scope, structural deployment and relational matrix of key stakeholders, roles, capacities and actions, indicative of discipline functions of *waste management*, as expressed in the guidance offered by peak international organisations.

3.5. Disciplinary Indicators Emerging from Documentary Evidence on the Materiality, Typology and Theoretical Constructs of Waste Management

Sources which explicate the *materiality* (i.e., the typology, composition, origins) and processes applied to the *waste stream* provide further insight into the disciplinarity of waste management [8,122]. Usefully some sources, such as the *Vital Waste Graphic* series [126] provide illustrations of these insights. This new data and its visual arrangement, provided alignment and confirmation, when examined alongside the previously discussed graphic series formulated by Seadon [50], (ref. Figure 1–5) in the process of constructing and evaluating *sustainable waste management systems*, which also featured *materiality*. Seadon [50] supports a systems view that, the interactive unit processes/elements of conventional waste management (i.e., generation, collection and disposal systems) are most effectively understood as, interrelating with each other, as well being linked to and influenced by, higher order national sub-systems (i.e., manufacturing, transport systems, land use patterns, urban growth & development, and public health considerations & system objectives (i.e., such as waste strategies and targets). The cited visualisations expresse both, interactivity between the physical and conceptual components of the *Waste Management System* (WMS—which includes social and environmental spheres), as well as provide a demonstration of integration and complexity, in the number (and nature/strength) of links between the components of the WMS [50].

Further contemporary indicators of the intensely integrative and complex systems thinking necessary for ISWM (and all that derive from this) are apparent in the documented guidance offered by other relevant peak international organisations, which variously reiterate and reinforce expressions of this phenomena. For example, the graphic in the International Solid Waste Association (ISWA), *Globalisation and Waste Management: Phase 1 Concepts and Facts* [127] report, illustrates the multiplicity of critical factors contributing to the converging of *Economy—Knowledge—Governance,* which is required for effective waste management. The reporting of both the merged *two triangles model,* illustrating the requisite six frameworks of *physical hardware,* interrelating with *governance software* (i.e., as sourced from the *Solid Waste Management in the World's Cities* [128]) and the *Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities* [89] combine to further reinforce this perspective and the discipline associations of waste management, with universal spheres such as governance, economics and development, etc.

3.6. Examining the Discipline Framings of Waste Management Industry Vocational Training Systems/Professional Development Programmes

Because they are structured around the real-world disciplines, skill-sets and subject knowledge, which are required of the people delivering the spectrum of tasks and knowledge systems making up the spectrum of contemporary professional services, vocational industry training regimes provide critical insight into the disciplinarity of (zero) waste management. For example, in 2007 the national industry organisation, the Solid Waste Association of North America (SWANA) began creating a series of 'Body of Knowledge' (BOK) to identify the critical skills and knowledge required for managers operating in specific disciplines [129]. Subsequently, other training and professional development initiatives by SWANA have focused on, for example the subjects of *GHG control programmes, waste-to-energy and post-disaster waste management (Haiti)* [129].

Similarly, but in a different national context and pedagogical framework, the New Zealand Qualifications Authority (NZQA) based resource recovery and solid waste industry training model [130–132] offer further disciplinary insights. New Zealand's NZQA industry training model was, in this period, based upon eighteen national qualifications encompassing multiple levels (2–5) of theory and practical skills, across multiple domains. As indicative examples, the data from the SWANA and NZQA professional development/vocational training regimes (NB: as might many other selected international options), provide a rich disciplinary insight, which combines with, confirms and enhances the *big picture* findings emerging from the review strategy.

3.7. A Selection of Examples of Other Miscellaneous Disciplinary Indicators/Insights

The first contribution in this cluster of other identified opportunities to examine the disciplinarity of waste, was a bibliometric analysis undertaken by [133] utilising the *Science Citation Index* (SCI) database, covering solid waste research literature, from a selected period (1993-2008). Alongside exploring current trends reflected in a variety of literary parameters, this analysis provides interesting insights into the disciplinarity of waste management, by developing a series of critical quantitative indicators. Further *academic* perspectives on the disciplinarity of waste, were gleaned from, a survey examining a ten-year period of waste related academic research undertaken in Swedish universities [134]. This study framed its reporting around five categories of *waste discipline*, namely: "production, recycling, collection and transport, treatment, disposal . . . " and "system analysis". The author also noted that, whilst conventional "technical" academic disciplines were the dominant contributors, "agricultural sciences, social sciences, economy and natural science", also involved disciplinary associations with waste [134].

Another similarly a study profiled the various disciplinary backgrounds of the team undertaking a multi-year, interdisciplinary research program entitled, *Towards Sustainable Waste Management* [135]. In respect of this program scenario, the authors commented on the complexity of merging different disciplinary approaches, to the required collective interdisciplinary purpose of modelling a range of policy instruments [135]. Waste management is both, identified as a critical element in the challenge of climate change, maintaining environmental quality and is described as covering a "vast field of critical human activities" [136]. Key *fields* in waste management are cited in respect of *generation, characterization, monitoring and treatment, practical* and *economical reuse* and ultimately *disposal*. This overview commentary on the waste industry reports that, "many professionals originating from diverse disciplines: engineering, biology, chemistry, economics, law, etc. are working in together" on shared objectives [136].

Examining the descriptive parameters of the, *call for abstracts* for presentations at waste related, industry conferences emerges as another interesting and informative window into the disciplinarity of waste management. For example, the respectively cited ranges of topic areas of the *Landfill Research Symposium* [137], alongside the scope of coverage, of the *2nd Symposium of the Asian Regional Branch of the International Waste Working Group* (IWWG-ARB 2015) [138] illustrate this further opportunity to examine the disciplinarity of waste management. Similarly, the descriptive parameters of the

call for abstracts for presentations across the annual international spectrum of dedicated zero waste themed industry/community conferences and workshops, also provide insight into how the respective organisers/organisations view, the subject demarcations of the industry, via lens of official points of professional gathering and information sharing. A final, arguably minor capstone contribution to this cluster of various *other* perspectives into the (inter)disciplinarity of (zero) waste management, is provided by Diaz in his 2006 book review of the, then newly published *Dictionary of Water and Waste Management*. His observation cites *environmental, mechanical, civil, sanitary . . . chemistry, microbiology, hydrology . . . public health . . . policy (EU directives) and legislation (U.S.)* as disciplines of "engineering" relevant to this sector [139].

3.8. Reviewing Selected Waste Literature Using 'Interdisciplinary' (and Other Derivatives) as a Search Term

The final coaxial element of this multi-perspective examination of the (inter)disciplinarity across the transitional waste → zero waste management spectrum, was provided by undertaking and then combining two correlated, but discrete reviews of relevant sources of literature. The two final elements of the review strategy (ref. Figure 2) involved, as described in this Section 3.8 title, searching, reviewing and categorising peer reviewed academic waste and resource management literature using 'interdisciplinary' (and other derivatives) as a search term.

3.9. Reviewing Selected Interdisciplinary Literature Using Waste/Zero Waste (and Other Derivatives) as a Search Term

The second of the two final coaxial elements of the review strategy involved searching, reviewing & categorising interdisciplinary literature using waste/zero waste (and other derivatives) as a search term. Utilising these delimited, targeted review elements, in this case examining coaxial perspectives, is consistent of other examples of discretely focused content analysis based approaches [140,141], and ultimately contributed a variety of interesting and relevant insights. In summary, the methodology represents an authentic scientific process, which is grounded in an extensive discussion of academic precedent and published finding and is attuned to delivering on the stated aim and purpose of this research.

4. Results: Examining the Disciplines and Interdisciplinarity of Waste → Zero Waste

The key findings from implementing the systematic review strategy (ref. Figure 2) are presented in the combination of Figures 1 and 3. Figure 3 integrates multiple sources of data and insight (ref Sections 3.1–3.9 *Methodology*) which collectively accumulate a significant body of relevant information, which enables a robust holistic 360° examination of disciplines contributing to (zero) waste management. In summation these illustrations offer insight on the composition and interrelationship of disciplines, aka the interdisciplinarity, requisite across the transitional waste → zero waste management spectrum.

The first step in this research process was the formation of an accepted general illustration of scientific disciplines, (ref Figure 1 & Section 3). This baseline illustration was advanced by highlighting disciplines, with an obvious connection/contribution to waste management (i.e., the overlay of yellow highlights in Figure 1). The subsequent process of compiling Figure 3, as an expanded, research informed graphic, illustrating the findings of the systematic review strategy involved, firstly deleting the science disciplines not initially assessed as having an obvious association waste management. This clarifying step created space within the original Figure 1 rubric for the addition of new data, i.e., findings of the systematic review exercise (ref. Figure 2 and the *Methodology* Sections 3.3–3.9). *NB: ultimately it emerges that* Figure 3 *becomes quite crowded with a lot of data, which both confirms the efficacy of the review strategy methodology and offers an early illustration of the complex interdisciplinarity requirement apparent in this sphere.*

As a result, Figure 3 reports a finalised compilation of *commonly recognised* (most now confirmed) and new research supported, literature-derived indicators of the disciplines and interdisciplinarity

across the transitional waste → zero waste management spectrum. This data is illustrated in relation to a generalised rubric of scientific disciplines. The content of Figure 3 can be interpreted via the following *legend* outlined in Table 2 (below) which identifies and orientates the associated references derived from, examining the seven selected sources of relevant information and insight into the (inter)disciplinarity of (zero) waste management.

Table 2. A legend explaining the colour coding system for Figure 3, which has been used to identify summary highlights and annotations for the disciplinary indicators and descriptions integrated within Figure 3.

Legend	Elaboration of the 'Colour Coding System' (i.e., 'Legend') Identifying the Highlights and Annotations for the Disciplinary Indicators and Descriptions Integrated within Figure 3.
YELLOW HIGHLIGHT	• The yellow highlight of 'Sustainability/Sustainable development' is carried over from Figure 1 as the key discipline location most directly correlated with waste management. Given this term *waste management* was not specifically identified as a stand-alone scientific discipline, the term *Sustainability/Sustainable development* is utilised as a title of a new, expanded bubble encompassing the review data illustrating the (inter)disciplinarity of (zero) waste management.
GREY HIGHLIGHT	• (Diaz, 2006; Lagerkvist, 2006; Münster et al., 2013; Valenzuela, 2008) collectively provide direct annotation of disciplines of relevant to their work area of waste [134–136,139]. (Chaves, dos Santos Jr, & Rocha, 2014; Massarutto, 2014; Moghissi, 1986; Senge, Carstedt, & Porter, 2001; Suess, 1983; Wilson, Smith, Blakey, & Shaxson, 2007) collectively provide direct annotation of disciplines complied in their interdisciplinary waste related research [142–147]. *NB: the wording from both data clusters is highlighted in grey in* Figure 3 .
BLUE TEXT	The accumulating interdisciplinary proposition for (zero) waste management, is underwritten by the recognition of zero waste and waste minimisation, within the proposed arrangement of interrelated sustainability initiatives and terminology (ref. Glavic & Lukman, 2007) [64] and the correlated designations associated with 'sustainable waste management' (ref. Kuehr, 2007; Seadon, 2010; UNEP et al., 2013; Varga & Kuehr, 2007), where the inherence of interdisciplinarity becomes progressively more explicit [50,75,76,89]. **Blue text** is utilised to illustrate this association and additional contribution to Figure 3 of the cited indicator terms, which are supported in sphere of literature, i.e., as explored in Section 3.3 namely: *The overarching construct and connection to sustainable development*.
RED TEXT	**Red text** is utilised to illustrate the provision of the next strands of evidence derived from the combined outcomes from Section 3.4. *Perspectives from International and national ISWM planning guidelines* and Section 3.5. *Documentary evidence on the materiality, typology and theoretical constructs of waste* (ref. Figure 2).
GREEN TEXT	**Green text** is utilised to illustrate the accumlating strands of evidence derived from the combinations of Section 3.6 *Examining the discipline framings of industry training and professional development sources*-and Section 3.7. *A selection of examples of other miscellaneous disciplinary indicators/insights*. In concert with the accumulating prior strands of diverse evidence from the systematic integrated review strategy, these findings are also merged into Figure 3 and further support for the proposition of waste (and hence zero waste) as an inherently interdisciplinary field.
BROWN TEXT	**Brown text** is utilised to illustrate the final strands of evidence originating from the coaxial exploration outlined in sections: Section 3.8. *Searching, reviewing and categorising waste literature using 'Interdisciplinary' (and other derivatives) as a search term*-and Section 3.9. *Searching, reviewing and categorising interdisciplinary literature using waste/zero waste (& other derivatives) as a search term*, which provide further contributions in support of the interdisciplinary proposition for (zero) waste management illustrated in Figure 3.

The combination of the general background and targeted systematic literature review strategy provides:

- A range of detailed terminology which encompasses and describes the component subjects, activities, terminology, business and material typology, linked and requisite to a broad spectrum understanding of waste and zero waste management.
- Evidence of broad socio-economic connectedness, i.e., the basic fact is that, every material type flowing through the spectrum of commercial entities and institutions making up the economy, eventually becomes waste for disposal, or is recovered an is re-circularised as a resource within the economy.

Collectively the data outlined in Figure 3, essentially expands on and details what the transitional waste → zero waste management spectrum is and does. This appears as both, an identifiable collection

of disciplines and also the multiplicity of interrelated and integrated spheres of activity. The waste → zero waste management spectrum of activity, appears as, at least as distinctive and comprehensive as, other scientific disciplines, which are recognised within the pantheon of science. The proposition emerges that, because (zero) waste management connects to and encompasses so many fields of knowledge/multiple disciplines, this can reasonably be described as an, interdisciplinary sphere.

The accumulation of disciplinary indicators outlined in Figure 3 are located across all parts of the generic scientific discipline framework (i.e., including in all *Social Science and Humanities, Applied Natural, Formal and Interdisciplinary Sciences)* as originally illustrated in Figure 1. Additionally, the incorporation of data from the systematic review strategy confirms this framework dispersion, as well as evidences a significantly expanded (zero) waste associated disciplinary contribution within the *Sustainability/Sustainable Development* discipline domain, which is identified and located within designation of *Interdisciplinary Sciences.* The centrality in Figure 1, combined with the expansion and elaboration in Figure 3, of the (zero) waste disciplinary indicators under the *Sustainability/Sustainable Development* disciplinary domain, within the *Interdisciplinary sciences*, evokes a rich picture of the intense interdisciplinarity of the waste → zero waste transition spectrum. This research output contributes a novel framing and a new evidence basis for further consideration, learning and ongoing questions and debate, in respect of the (inter)disciplinarity of (zero) waste and the issues and opportunities associated with advancing this.

Table 3. A brief empirical summary of the distribution and level of *attribution and confirmation* provided via the review strategy data, of prior disciplinary *associations*/connections to (zero) waste (ref. yellow highlights in Figure 1). *NB: for consistency sakes a simple rules-based system for counting was applied in developing these indicative metrics.*

Key Discipline Demarcation	Disciplinary Indicators for Waste → Zero Waste/Confirmation
Social Science and Humanities	Social Science (32/25) & Humanities (9/4) = 41/29
Applied Sciences	33/24
Natural Sciences	Physical Sciences (30/21) and Life Sciences (20/11) = 50/32
Formal Sciences	5/0
Interdisciplinary Sciences	34/27
• Sustainability/Sust. Dev. expansion bubble	Blue (59/33), Red (114), Green (49) & Brown (43) = 265

Comment: In respect of the originally identified 163 'waste associated'disciplines, which were retained in the generalised baseline rubric of scientific disciplines, 112 or approx. 68.7% were confirmed through the execution of the review strategy. As discussed in Table 2 these confirmations are highlighted with grey shading. In addition, the review strategy (ref Figure 2) produced content which enabled the creation of a new greatly expanded 'Sustainability/Sustainable Development' bubble (i.e., a total of 265 new (zero) waste disciplinary indicators) within the existing *Interdisciplinary Sciences* bubble. This Table 3 and Figure 3 (below) identify and discuss the source of the four main tranches of data and the waste → zero waste disciplinary indicators which emerged through the research process. *NB: Within the initial* Figure 1 *the total number of recorded disciplines vs the highlighted waste management associations were respectively: SS&H -respectively 50/32 & 27/9, ApSci 61/33, NatSci-Phys 75/30 & Life 51/20, FrmSci 7/5, IDSci 65/34 = 336/163 (i.e., an association ratio with waste management of approx. 48.5%).*

Whilst widely scoped, the systematic integrated review strategy utilised in this research was also, by design, deliberately delimited. The review strategy was not intended and is not presented as, a fully comprehensive, in-depth conventional literature review exercise, as this was beyond the scope of this research. However, the approach of examining and combining multiple, diverse sources of data, has in the sum of its parts, achieved a comprehensive breadth and collective adequacy in securing and illustrating important new insights into the disciplines and interdisciplinarity of (zero) waste management. The sequence and procedure in developing Figures 1 and 3, goes some way towards confirming the simple, high level assertion that, as a subject/discipline/field, waste (and hence, even more so, zero waste) management, exhibits an inherent complexity and sense of interconnected *everythingness* [100].

In particular, as a final result Figure 3 illustrates a significantly expanded and more complete picture of the high number of contributing disciplines (i.e., multi-disciplinary) and as well high degree of interdisciplinary integration across a conventional, general rubric of science disciplines. For example, the technology and practice of landfill management, which is a mainstay of ISWM, can be seen as connected to both *Physical* and *Life* demarcations of *Natural Science* [i.e., via earth science (i.e., location and establishment) and to environmental chemistry (i.e., ecological monitoring and compliance) as *Physical sciences* and to soil or marine biology (i.e., soil, stormwater and ground water contamination) as *Life sciences*]. Similarly, landfill management can also be connected to *Applied Sciences*, by for example, the disciplines of civil engineering and public health. Connections to the *Social Sciences and Humanities* can also be discerned for landfill management, via the likes of environmental anthropology, public policy and business administration (i.e., as *Social Sciences*) and history and archaeology aspects [102] (i.e., as subject within *Humanities*). Similarly, landfill management can be connected to *Formal Sciences*, via the statistical element of data collection and monitoring, as well as in a number of ways to the *Interdisciplinary Sciences*, via interrelating with likes of climate sciences (methane emissions) and urban planning, etc.

Collectively the findings of the review strategy which are outlined in the arrangement and combination of Figures 1 and 3 have, even at this scoping level of investigation, produced a broad array of indicative discipline and interdisciplinary terminology, references, descriptors and insight and as such achieve the aim of this research. The final iteration of Figure 3 illustrates both, a common orthodox of disciplinary connections/contributions, as well as those emerging from the combined elements of the search-review exercises outlined in Figure 2 and discussed in Sections 3.1–3.9. The resulting array of subjects/disciplinary indicators, which present as contributing to (zero) waste management, are both, dispersed across the generic baseline rubric of scientific disciplines, as well as richly augment the demarcation of *Interdisciplinary science* within this.

The illustrative compilation provided in Figure 3 evokes both, an interesting and extensive picture of the discipline connections and (inter)disciplinarity of (zero) waste management, as a subject and practice. However, at this delimited level of investigation, this finding offers only partial evidence and progress in fully resolving questions around the (inter)disciplinary status of (zero) waste management. Without, at this level of investigation, securing evidence identifying and locating waste management as a stand-alone scientific discipline, the simplest inference (as has been illustrated) is to accept this multidisciplinary connectivity and the resulting implication that the transitional *waste* → *zero waste* management spectrum is an inherently interdisciplinary sphere of science. These results contribute new insights in understanding why waste issues have reached the numerously described point of global crisis [9,35]. It can be argued that this complex and entrenched environmental imperative [7,8] is being approached, via an unresolved and outmoded conception of the complete disciplinary requirement for fully encompass the holistic issue of waste. Further, that what disciplines are contributing, are engaged at less than the advanced level of inter → trans disciplinary synergy necessary, to catalyze breakthrough levels of innovation and inspiration to address waste issues. Creating a new data-set to evidence and illustrate these considerations, achieves the research purpose of providing a platform for understanding and discussion enhancing the understanding and future employment of interdisciplinary theory and practice might be enhanced so as to generate progress on acute global environmental problem.

Figure 3. A schematic which illustrates documented indicators of associated and contributing disciplines connections - and the (inter)disciplinary proposition of (zero) waste management in relation to a background rubric of scientific disciplines. NB: Glavic and Lukman's full glossary of terms from their *Review of sustainability terms and their definitions* is: "CP, cleaner production; DE, degradation; EA, environmental accounting; ED, eco-design; EE, environmental engineering; EI, ethical investment; EL, environmental legalisation; EMS, environmental management strategy; ET, environmental technology; E2, eco- efficiency; FX, factor X; GC, green chemistry; HS, health and safety; IE, industrial ecology; IPPC, integrated pollution prevention and control; LCA, life cycle assessment; M, mutualism; MRU, minimization of resource usage; P, purification; PC, pollution control; PO, policy; PP, polluter-pays principle; PSS, product service system; P2, pollution prevention; RC, responsible care; R, reporting to the stakeholders; RE, recycling; RF, remanufacturing; RG, regeneration; RP, repair; RU, reuse; RV, recovery; R2, renewable resources; SC, sustainable consumption; SCM, supply chain management; SD, sustainable development; SP, sustainable production; SR, source reduction; SRE, social responsibility; VEA, voluntary environmental agreement; WM, waste minimization; and ZW, zero waste" [64].

5. Discussion and Conclusions

5.1. An Interdisciplinary Proposition for (Zero) Waste Management?

The combination of results and the following discussion combine to fulfill the aim and purpose of this research. Hopefully these findings will provoke further research interest and engagement in the nexus of, complex environmental phenomena, i.e., such (zero) waste, and the recognized opportunity inherent to progressive interdisciplinary education, research and practice. An initial key observation enabled in the compilation of Figure 1 (i.e., which illustrates a contemporary, generic, five-part rubric of scientific disciplines, based upon *Applied, Natural, Formal, Interdisciplinary and Social Sciences & Humanities*) is that, the overlapping cell which demarcates the group of named disciplines considered part of the *Interdisciplinary Sciences*, forms a relatively a large component of the overall arrangement. The relative prominence of the interdisciplinary sciences, within this illustrative rubric of scientific disciplines, reinforces the argument that interdisciplinarity is an intellectual megatrend, encompassing both, *grand theorem, cosmology*, as well as a continuing *subtle restructuring* of knowledge, in response to epistemological crisis [111]. Examined within the interrelated spectrum of intra, cross, multi, pluri and transdisciplinary research activity, the quest for interdisciplinarity can be conceptualised as both: a progressive, contemporary phenomenon, as well as part of an archaic epistemology of convergence, grounded in the ideal of synthesis and unity of knowledge and origins of western scientific thought [2,50,111].

Within Figure 1, the illustrated the result of the described review - compilation exercise, the term *waste management* does not emerge as a designated, stand-alone discipline. Given the historic tenure and contemporary stature of the activity of *managing waste* (i.e., which today warrants a cluster of named scientific journals) this apparent lack of definition and recognition raises various questions. The combination of Figures 1 and 3, illustrates a wide assortment of terms, indicators, or conceptions, which can be identified and assembled in connection with the disciplinarity of waste management. However, it is not clear that the industry and research community has yet reached the point of establishing and justifying a definitive universal theoretical disciplinary convention for waste management. Given this observation, preceding the word *waste* with the word *zero* (with all controversy, disruption and augmentation inferred in this combination), appears only to aggravate the sense of confusion and omission. This lack of clarity presents as further impediment in defining and ascribing disciplinarity across the broader future focused and dynamic, transitional *waste* → *zero waste* management spectrum.

However, despite the delimited scope of this review strategy, it appears reasonable to generally propose waste and zero waste management, either individually or, collectively as a spectrum of sustainable waste management brands/movements/initiatives (herein annotated by the extremities, waste → zero waste) as, interdisciplinary practices. As such, the transitional waste → zero waste management spectrum can be identified and understood as a complex, interconnected, composite of discipline(s) and be located inside the demarcation of *interdisciplinary sciences*, within an overall generic rubric, detailing and relationally illustrating scientific disciplines. The dynamic spectrum of sustainable waste management practices/brands/movements, which can be orientated between the extremities of historical waste management and the future aspiration of zero waste, have overlapping rhetoric, cognitive DNA, practical mutuality and causes in common. Confirming and then capitalising on the recognized value proposition of interdisciplinarity, across this collective waste → zero waste transition spectrum, presents as a significant new strand of opportunity, aligned with the cited potential for addressing the globalised issue of waste [12,63,148].

However, in practice, this potential appears to be undermined by numerous *real-world* constraints. For example, contesting against vested commercial imperatives/interests, embedded social conditioning, political dysfunction/inertia, as well as the dissipating effects of theoretical schism and disciplinary chauvinism [22]. Interdisciplinary practice is described as requiring a tolerance of ambiguity, acceptance of multi-discipline adequacy, which necessitates humility, holism, reflectiveness, a willing enjoyment of

diversity, learning and creative collaboration. [3]. Further research to better define the core disciplinarity of *waste management*, as well as how this expectation and composition changes in moving towards the → *zero waste* end of the transitional spectrum, appears as a critical priority. This assertion provokes the question: might resolving disciplinary status and enhancing understanding around interdisciplinary practice across the waste → zero waste transition spectrum, enable more effective collaboration and assist overcoming the barriers to progress in addressing the critical global issue of waste?

Conversely, it might be argued that waste management is suitably and sufficiently recognised under the umbrella discipline of *Sustainability/Sustainable development*, which is already identified and annotated as a genre, within the *interdisciplinary sciences*. Within their arrangement and illustration of the terminology and definition of sustainability, Glavic and Lukman [64] formalise the connection, identification and location of both *waste minimisation* and *zero waste* within this genre of activity. However, the adequacy of these two terms (both of which infer a *green*, rather than *disposal* orientated worldview) in representing the totality of all the activity associated with (zero) waste management, is questionable. Alongside the previously mentioned, historic tenure and scientific stature of traditional waste management, this apparent incongruity is compounded by the recognition that, both sustainability/sustainable development [149,150] and the concept and practice of interdisciplinarity [111,118] are relatively recent phenomena, which postdate the archaic consideration and formation of distinctive *management practices,* responding to both the issues and opportunities of waste [16]. Questions about the suitability of *Sustainability/Sustainable development* as an all-encompassing disciplinary proxy, are further compounded by the numerous indicators (illustrated in Figure 1, by yellow highlights) that the collective activity of (zero) waste management, connects to and draws upon other recognised disciplines across all demarcations in the generic rubric of scientific disciplines.

The combination of Figures 1 and 3 illustrate both, significant discipline connectivity and an apparent absence of an established (inter)disciplinary convention for (zero) waste management. However specific commentators do make deliberate reference to various disciplines associated with their specific work and general perspective around waste, with at least one deliberately describing solid waste management as inherently "interdisciplinary" and "involving many branches of . . . science" [147]. Aligning with this viewpoint Bing et. al., observe that, "waste recycling is a multi-disciplinary problem" and as such, requires simultaneous multi-level consideration [151]. A further illustration of this perspective, is the assertion that an interdisciplinary approach is essential for the development of successful *Construction and Demolition* (C&D) waste management [152]. This point is reinforced, by the findings of a literature review, covering eight scholarly journals, which outlines how C&D is viewed as a *discipline* within waste management [153]. The authors discuss how, from a research perspective the *discipline of C&D* is explored down the following sub-discipline channels: *reduction, reuse, recycling*, *waste management in general* and *related human factors* [153]. An implication arising from this view is that, potentially other disciplines and sub-disciplines should also be considered and classified for (zero) waste management.

Interdisciplinarity has been associated with innovation and break-through in addressing real-world problems [1,4,5]. When this assertion is examined alongside the cited under-performance of waste management globally [8,154], it evokes a succession of questions such as: how well is interdisciplinary theory and practice is understood and outworked within (zero) waste management? What needs to be done to improve this? What might be the result of any improvement? Within a traditional waste management paradigm, the disciplinary practices of the *Social Sciences and Humanities*, sometimes appear to be treated as optional and subservient, rather than as an integral priority, contingent with *reduce* being located at the top of the waste hierarchy. For example, community consultation sometimes appears flawed, co-opted and under resourced. Whilst, education and behaviour change, sometimes appear retrofitted to coerce conformance with rules (i.e., reduce contamination), or repair social engagement, after ill-conceived, top-down, technocratic approaches go awry [128,155]. Possibly, such scenarios exist because, despite supposedly being the least and last priority of the waste hierarchy, *residual disposal* still

dominates the systemic practice and financial calculus of the conventional waste management industry? A strong value proposition exists around shifting, focus, effort and resources from the bottom to the top priorities of the waste hierarchy. Enhancing interdisciplinary understanding and engagement, appears as a key opportunity to advance this, via enabling the requisite disciplines/knowledge spheres to coalesce, synergise and in this, to generate innovation and breakthrough progress across the waste → zero waste transition spectrum.

5.2. Reflections on the Targeted Review Strategy and the Illustration of Findings

The systematic integrated review strategy (illustrated in Figure 2) was developed and implemented in order to explore multiple sources of data and diverse insights (ref. Sections 3.1–3.9), relevant to examining the composition and relational arrangement between disciplines (aka the interdisciplinarity) contributing to both conventional waste and zero waste management approaches. Strengths, weaknesses and deliberate delimitations in the holistic, 360° explorative approach employed in this methodology, are acknowledged. A strength of this approach is the blending of conventional literature review, with a more unconventional prospecting of other opportunities for gleaning insight into the interdisciplinarity of (zero) waste management. The model employs flexibility, open mindedness (i.e., avoiding myopia, false certainty and overstatement based on a limited field of view) and avoids precluding what insights might emerge as important [2,22]. Whilst this scope of enquiry can be considered quite open, it is also acknowledged that other, different options for gathering additional insight, will also exist. For example, reviewing the outputs, contributing networks and process of named interdisciplinarity research and education centres [113] would provide a further and as yet, largely unexplored access point for identifying and analysing (zero) waste/resource management related interdisciplinary research.

Conversely, a potential weakness and limitation in this review methodology, is the trade-off between the breadth and depth of insight. For example, in the systematic literature review element, a practical limit of three key journals were selected (ref 3.8. & 3.9. where the research precedent is discussed). This provided an indicative representation of the overall base of scientific publications from the extensive, dynamic and evolving field of (zero) waste management. Similarly, just two indicative examples of national vocational training/professional development structures (i.e., the U.S. SWANA and models) were selected from the many international options, which potentially offer insight into the disciplinary demarcation, contributions and interdisciplinary formation of (zero) waste management. On the basis of these prescribed delimitations, the findings of this research are communicated as *indicative and emerging*, rather than definitive and final. In canvassing and communicating this broad, diverse, but also delimited perspective on the disciplines and interdisciplinarity of (zero) waste management, a key recommendation is then, for further research to be undertaken in this sphere, to address ongoing questions and the extraneous implications, which arise from these initial findings.

However, despite the cited delimitations, the systematic integrated review methodology (ref. Figure 2) in combination with the baseline review of interdisciplinary (and some transdisciplinary) waste management literature, secured a significant body of relevant information and insight for this research. For example, one finding which exceeded the reporting capsity of this single article, was the proposal and discussion of an initial fifteen tabularised descriptive categories *(namely: 1- Discussion of the design of multi- stakeholder, whole of supply chain product stewardship programmes (e.g., WEEE) 2-ESD in a University setting, 3- C&D waste management, 4-food waste, 5-waste auditing and MFA with a social dimension, 6-remediation technology development, 7-policy development and review, 8- terminology (reuse), 9-education for sustainable development (ESD), 10- waste/resource-modelling/planning/management, 11-technology, 12-leadership viewpoints (Ed), 13-design for recycling (sustainability), 14–environmental, human health and 15- waste art/arts recycling)*, which emerged from the coaxial analysis of how, *interdisciplinary* research has engaged with the subject of (zero) waste management and how, interdisciplinarity is interpreted in the (zero) waste management sphere research. It seems likely that extending this search, review and evaluative exercise will further expand our insight around the inter-association of (zero) waste management and (inter)disciplinary research.

Table 2 provides the *legend* for interpreting the colour coding, which highlights the procedure and decision making, which enabled the initial result in illustrated as Figure 1, to be iteratively loaded with data from the review strategy (see Figure 2) and to be finalised as Figure 3. The first layer of information merged in the formation of Figure 3 are direct discipline indicators (i.e., grey highlights) communicated by the cited authors. Alongside the cluster, located within the expanded *Sustainability/Sustainable development* bubble, within the designation of *Interdisciplinary Sciences*, these disciplinary indicators are spread across the other demarcations (with the exception of *Formal Sciences*), within the generic rubric of scientific disciplines. Table 3 quantifies this spread and illustrates a reasonable level of confirmation around the original attribution of disciplinary association with waste management. The subsequent layers of information from the sources/authors identified and respectively outlined in the demarcations of blue, red, green text of Table 2, provides a wide variety of wording, drawn from the component theory, subjects, activities, business and material typology, all of which offer various indicators of the disciplinarity associated (zero) waste management. The final component of evidence around the (inter)disciplinarity of (zero) waste, signified within Table 2 as brown text, is derived from the focused, coaxial search and review of relevant spheres of literature, targeted as an opportunity to contribute further insight. Ultimately, all of this data converges in illustration and support of the tentative interdisciplinary proposition outlined and arranged as Figure 3.

5.3. Observations Emerging from the Research Findings

As a final summative result, Figure 3 illustrates (with detailed terminology) the accumulation of (inter)disciplinary indicators/connections, related to (zero) waste management. This provides a significantly expanded and ultimately a more complete and clearer (albeit complex) picture, of what constitutes the disciplinarity of the transitional waste → zero waste management spectrum as a dynamic and evolving field of science and practice. Whilst, the combination of Figures 1 and 3 provide a new, comprehensive and interesting information basis for understanding the (inter) disciplinarity of (zero) waste management, this result is not asserted as representing a definite final set of disciplines and sub-disciplines making up either traditional waste management, nor the *spectrum of sustainable waste management movements*, through to most extreme and disruptive aspirant in this sphere, *zero waste management*. Hence, this research exercise was not able to fully resolve the apparent in omission in defining and attributing (zero) waste management as a scientific discipline.

However, it is observable that, individually and or as a collective, this sphere of activity appears at least as identifiable, comprehensive, historically tenured, social-economically important and environmentally critical, as other named scientific disciplines, which appear to be formally recognised within the pantheon of science. Figure 3 provides some substance for and explicates the proposition that, if not in its own right, then within the *Sustainability/Sustainable development* demarcation, (zero) waste management can be identified and attributed within and as an *Interdisciplinary Sciences*. Given the acknowledged delimitations of this methodology, it is likely further, more comprehensive research would supplement the indicative list of discipline connections and add weight to the current conclusion. Namely that, that because the field of knowledge around the extremities of waste and zero waste interconnect within an encompasses a multiplicity of disciplines, the dynamic, transitional waste → zero waste management spectrum can reasonably be ascribed, as Suess previously did [147], as an interdisciplinary field.

An interesting observation emerging from this overview exercise is that, waste related projects undertaken in either a *developing* country context and or, from the academic perspective of *development studies*, appear to more readily identify the requirement for interdisciplinarity. This observation may be related to, the role identified as being historically undertaken by the OECD, in the formation of interdisciplinarity at the forefront international *problem-based* (i.e., poverty and underdevelopment) research imperatives [2,5,156]. Lynch & Schepers [157] similarly report how, within the waste aspect of the co-operative *Biological Resource Management for Sustainable Agricultural Systems* research programme, the OECD deliberately fosters *multi and cross* - disciplinary approaches (i.e., specifically to ensure the

interface social and political sciences, as well as for sustainable technology evaluations, models and databases). One of the high level learnings from the history of aid and development research and practice, is the necessity of participatory collaboration, as a foundational concept [158]. This experience appears to have positively influenced, how waste related research and practice is undertaken and reported in the context of development studies. In turn, these normalisations may have ensured that the field of *aid and development* has been influential in the formation the contemporary practice of interdisciplinarity [22,159], including in the sphere (zero) waste management.

A further observation is that the term *interdisciplinary* does appear to *mobilise* as a connecting theme within certain tranches of research publication (i.e., the bio-remediation of oil waste). It appears that once the interdisciplinary connection is explicated within a scientific publication, this then proliferates further, via ongoing research processes, reciprocal citation and reoccurring references, etc. The countervailing instance and omission also appears to occur, i.e., where interdisciplinary practice is reasonably self-evident, without being uniformly and explicitly identified and referenced as such. This appears to become a reoccurring omission in the required explication of the associated research theory and practice. For example, in *discussion of the design of multi-stakeholder, whole of supply chain product stewardship (PS) programmes*, three examples of research make specific their understanding of the inherent interdisciplinarity, or the potential of interdisciplinary approaches to support this this work area [145,160,161]. If these arguments are sound, then to some degree, the point will also generally hold true, for many more of the hundreds of other research projects active in the sphere of product stewardship and extended producer responsibility (PS/EPR), who have not similarly identified and exploited this, as an opportunity to improve their research process.

It is also recognisable that the need and requirement for interdisciplinary research practice, is a reoccurring theme in a cluster of editorial/industry/academic leadership-based publications. This indicates that, at least in the editorial/leadership sphere, a sense of the general importance of interdisciplinarity, is accepted and being promoted [162,163]. Potentially, if the challenge and importance of interdisciplinary perspectives, being promoted within leadership platforms, is taken-up then, in future, the quantity and quality of interdisciplinary practices should proliferate amongst (zero) waste management researchers.

As discussed previously, the illustration of the (inter)disciplinarity of (zero) waste management offered in Figures 1 and 3, raises questions such as, how the disciplinary components of (zero) waste management can and should engage together? Will improving interdisciplinary engagement, enable the sector to reverse the perceptions of under-performance of waste management globally [8] and with this to, reduce environmental impacts, enhance human health/prosperity, address climate change and to realise a significant contribution to the achievement of the UNSDG goals [85]. Enhancing understanding and normalising good interdisciplinary (and potentially even the transdisciplinary) practice within the (zero) waste management sector, appears as a critical opportunity for achieving the commonly held aspiration for breakthrough and progress.

One observation, which reinforces commentary on the desirability vs. difficulty and rhetoric vs. reality of achieving genuinely transdisciplinary research [2,22,164] is that, there appears to be far more research practice in the waste work area, which is described as, interdisciplinary, rather than transdisciplinary. Cultivating interdisciplinary knowledge, skill and experience presents as the gateway to then, enhancing and moving beyond this into the largely uncharted potential of transdisciplinary research and practice. In respect of *sustainable waste management*, transdisciplinarity is reported as necessitating: a systems view, management coordination between all levels and types/streams of waste and complex interactivity between the physical and conceptual components of the waste management system (including the social and environmental spheres) [50]. Transdisciplinarity is described as aspiring to overcome paradox, schism, historical deficiency and disciplinary chauvinism, in order to synthesise new, socially and scientifically robust knowledge, from transcendent creative processes, hybrid modes of inquiry and a pluralism of method [2,22,165]. Klein [2] argues that

transdisciplinarity has always been about, "imagining futures" and relates this to the overlapping discourses of *transgressive* and *post-normal science* [166,167].

5.4. Concluding Summary

Today has been conceptualised is as a "parenthesis in history" [168], in which society is currently caught between a traditional, but now outdated and unsustainable *waste* centric model and another, yet to fully actualised, *next* model, founded in the principles of environmental sustainability. The adoption of the *waste* → *zero waste* terminology expresses this concept of a past → future transitional space, between what isn't working well enough - and the proposed future hypothesis of, what will work better and be more sustainable [168,169]. The heterogenous global zero waste community of practice, is part of this *next* sustainable waste management cluster and plays a part (in synergy with, for example, the movement for a circular economy) in prospecting and driving progress beyond the current, known thresholds of achievement [32]. The global quest to achieve more sustainable resource/waste management can be understood as involving multiple dimensions, geographies and technicalities, as well as historical, contemporary and economic development contexts, which interface with the complex reality of degraded physical environments and biodiversity and impacted human cultures and socio-economic systems [32]. Arguably the scale of complexity and challenge of realising of genuine problem solving and change making exists, beyond the scope of any single (or even narrow cluster of) discipline(s). This *demand framing*, presents as requiring revolutionary insight, regenerative technologies, radical socio-economic restructuring and where necessary, circumventing inefficacious disciplinary convention and authority. The requisite *disrupt–transform* scenario, appears to fit that, presupposed in transitioning to interdisciplinary and then into highly integrated, transdisciplinary research and practice [50].

It is interesting to correlate transdisciplinary discourse with how zero waste can be a similarly conceived/interpreted as being at the pioneering, hyper aspirational end of a dynamic continuum of global activity, provoking transition from *managing* → to *eliminating* (aka zero) waste. Alongside addressing the attendant issues and consequence of waste, the vexing duality of zero waste seeks to simultaneously confront *issue/cause* and to catalyse innovation and progress in the overarching quest around climate change and sustainable development [81]. Respectively, transdisciplinarity is emerges from and hence is, dependent on conventional disciplines and zero waste arises out of and tacitly relies on traditional waste management practice. In this, both can be aligned in seeking to build on – yet simultaneously transgress and transcend the incumbent dysfunction and limitation of *known* disciplinary foundations. The discourses of transdisciplinarity and zero waste can be orientated and allied, as part of an array of reactionary "cultural critique, socio-political movements, and conceptions of post-normal science and wicked problems" [2], (p. 68).

It is observable that transdisciplinarity and zero waste similarly seek aspirational extremities: i.e., synthesising new theories and practices, maximum collaboration involving multiple disciplines and stakeholders, crossing epistemological boundaries—via a plurality of methods and in accepting that, failure as a requite part of experiment and quest [22]. In not appearing over-burdened by the immediacy of result, ahead of incitements such as *journey, learning and progress* [22] it can be argued that, transdisciplinarity and zero waste are both inheritors of the freedom of opportunity that the perception of *systematic failure* offers to respondents. Consequently, both appear subject to similar lines of opposition and critique, for example, perception of over-inflated, unrealistic levels of ambition and for valuing and maximising *non-professional* engagement within scientific collaboration, targeting real-world problems [22].

Engineering progress along the transitional waste → zero waste management spectrum represents a significant and fundamental escalation in technical ambition and complexity. Foremost, this is because everything diverted from conventional comingled collection and disposal has to, instead be handled on the basis of resource/hazard composition and deliberately matched to specific and appropriate technical processes, synchronised with the respective physical properties. Progressing

towards zero waste and a circular economy, is exponentially challenging because, conceptually this encompasses the *upstream* dimensions of (re)designing the fundamental nature and objective of all products/materials, markets, production and consumption and the roles, responsibilities and structure of interactions between the public, government and private sectors.

Actualising these *upstream* zero waste considerations, compounds the demand for accelerated development of the matrix of *downstream* (so called *end of pipe*) infrastructure and services for recovering and circularising materials flows, which are otherwise mostly, lineally predestined for disposal [32]. This challenge requires the positive integration of many diverse strands of theory and practice, arising from for example, economists, designers, engineers/technologists, producers/retailers/marketers, politicians, business-people, development practitioners and natural and social scientists and environmental activists and consumers. All of whom are necessary contributors in the converging debate, research and practice underwriting the potential for, further progress along the waste → zero waste transition spectrum [31,32].

The findings of the explorative review strategy compiled as Figures 1 and 3, illustrates the intense (inter)disciplinarity of (zero) waste management and evokes the sense of interconnection and *everythingness* cited around waste [100]. It seems likely that further, more in-depth research examining this phenomenon, will enhance and further detail, rather than erode this view. However, in illustrating the many indicators of contribution and interconnected disciplinary association with (zero) waste management - within a generic rubric of scientific disciplines, these findings also serve to illustrate a lack of clarity and formal definition about how all these elements might work more optimally together.

Better defining the sector's interdisciplinary (and potentially transdisciplinary) needs and practices is required to realise potential across the spectrum of *conceptions and contenders* for driving progress towards a more sustainable (zero) waste management and a circular economy. In particular, inter and transdisciplinary understanding and practices, appear especially important in seeking to actuate the upper echelons of priority, expressed in the ubiquitous, yet highly contested and iterated *waste hierarchy* concept. The key implication from this research is, not if the discussed variants across the transitional *waste* → *zero waste* management spectrum are interdisciplinary, but rather, is the quality of interdisciplinary comprehension, procedural design and practice of sufficient, quality to realise the cited potential for benefit [114] and break-through, in respect of societies biggest questions and issues [2,118,170].

Funding: This research has no external funding.

Acknowledgments: The author would like to acknowledge and thank Chris Anderson and Associate Robin Peace for their support and guidance throughout this process.

Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. A compilation and interpretation of information related to the disciplinarity of (zero) waste management, sourced from an indicative selection of national/international waste management planning guidelines.

STAKEHOLDERS	ROLES/CAPACITIES/ACTIONS-INDICATIVE OF *DISCIPLINE* FUNCTIONS.
National governments	Developing, coordinating, implementing and reviewing *National Waste Management Strategy* (NWMS), developing supporting legislation and regulation leading consultation, engaging in the development, signing and maintenance of international conventions & treaties.
Government sectorial agencies (e.g., environment, industry policy, infrastructure and planning, education, health).	Policy coordination, coherency, integration and leadership, Regulatory bodies (Environmental Protection Bureau, etc.), maybe responsible for one or more waste streams such C&D, Medical / Biosecurity, etc.

Table A1. *Cont.*

STAKEHOLDERS	ROLES/CAPACITIES/ACTIONS-INDICATIVE OF *DISCIPLINE* FUNCTIONS.
Regional & Local govt. as key practitioners (accorded by legislative responsibility) of waste management globally	Manage and/or undertake various degrees/versions of ISWM of MSW (including 5R waste hierarchy initiatives i.e., reduce, reuse, recycling, recovery and residual disposal etc.) and critically participate in the coordination of governance oversight.
In the interface between these stakeholders—exists the possibility/demonstration of *Public Private People Partnerships* (PPPPs)	
Also in this interface Industry associations, may play a major role in thought leadership, debates /lobbying repositories of information on waste issues, via the individual companies and government/community entities that make up their membership.	
Public sector waste, resources and hazard generators:	i.e., Hospitals and other health care facilities, schools/universities/research centres/laboratories, public facilities (sports grounds, street sweeping and cleaning), water treatment and sewage treatment facilities, airports/ports/marinas (ships and aircraft).
General commercial/private sector waste, resources and hazard generators: as a major influencer of waste & management	Decision-making around products, processes and destination of material flows, via: product design and life cycle, production of goods and materials (i.e., input sources, selection & resources consumed per unit of output), packaging, distribution & marketing. As servicer purchaser/user (i.e., retail, food, transport manufacturing ops.) and provider (i.e., designing funding and supplying facilities and equipment for resource recycling and waste collection handling and disposal)
Community waste, resources and hazard generators: individuals, households, groups play a central role in waste management,	Consumers (whose awareness, motivation, cultures and choices may be disparate and uncoordinated) of advertising demand drivers and then purchasers of goods and services, who become custodians of resources and hazards and the waste and resource generators via *separation at source* or discarding materials. Active/non active learners/adopters, selectors (via public consultation), funders (collective public/private) and users of the waste/resource management. Potential participants in the design, monitoring and implementation of programmes
In the interface: Political figures at different levels of government, heads of companies, religious leaders and popular figures from mass media engaged as *opinion leaders/influencers* and *decision-makers* influencing community and business attitudes and behaviours.	
In the interface: *Non-government Organisations* (NGOs) are influential agencies, information dissemination, awareness raising, communication of advisory and of either programme support or conversely environmental & social activism. NGOs may provide organised services via groups, initiatives, cooperatives and community enterprises resulting in waste reduction i.e., via *third/2nd hand sector/reuse - resale* programmes. Because NGOs are generally viewed as trusted independent and authoritative they are critical in adjudicating the acceptability of waste management policies and programmes.	
In the interface: Waste experts and academics (university lecturers and researchers) contribute knowledge and advances in both scientific and social aspects of waste management, e.g., on technologies, on interactions among stakeholders and on decision-making and monitoring tools.	
In the interface: Teachers and other educators play a part in community engagement and changing consumer behaviour, and through the education process supply the human resources necessary to manage, regulate and maintain waste management operations. Sometimes education can contribute through the influence of students, in particular with regard to their families.	
In the interface: Other sectors can also have a role to play, depending on local circumstances. Unions, for example, can sometimes be important players, as can mass media, through the delivery of information or education.	
Waste management and recycling service providing organisations	Materials recovery and recycling practitioners (formal/informal, private/public) sorting facility design, technology selection, configuration, operation and maintenances. Recyclate traders/exporters. Waste and litter collections, transport, landfills and incinerators. Secondary resource (import/export) and potential W2E energy consumers (e.g., metals refining, cement, mining) able to utilises waste/resources and inputs to production.
Informal/formal, men/woman waste and recycling workers	Contributes labour to the reuse, sorting, recovery and recycling of useful materials and products found in the waste stream In developing countries the informal sector is in effect a transitional formation of an industry/cooperative sector (i.e., the skills and abilities cover resource picking, collection and transfer systems, handling and processing facility, wholesale trading operations, micro reprocessing mills/factories adding value to recovered resources, retail and delivery operations of finished recovered, remanufactured and recycled products

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