sustainability

Review

Dishwashers: Literature Review to Summarise the Multi-Dimensionality of Sustainable Production and Consumption

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Abstract: An automatic dishwasher is a water-using, energy-demanding contraption with 40–50 different component parts fashioned out of different materials—metals and non-metals—which over the last 70 years has evolved in its role as a comfort-enhancing, convenience-providing, time-saving white good in the kitchen of the modern urban household, especially in the countries of the developed world. Its lifecycle, which spans about 12–13 years on average, lends itself to research in a variety of sustainability aspects—politico-legal/regulatory, economic, environmental, social and techno-functional—and fields—thermodynamics, fluid mechanics, acoustics, economics, chemistry, microbiology, materials science, design engineering, wastewater treatment, energy engineering, consumer behaviour, and, of late, sustainable consumption and production. The end goal of this review is to present the automatic dishwasher—almost ubiquitous and taken-for-granted in the western world these days—as a candidate for progressive research and development, resulting in its continued evolution. The author facilitates this by providing an overview of the different aspects of sustainability addressed by researchers thus far. It at once reinforces the importance of transdisciplinary research, finds answers to a clutch of 'what', 'why', 'where', 'how', 'who', and 'when' questions, and reminds us that improvement/s in one aspect must not undermine or thwart those in any of the others. It is the first of its kind, as far as the automatic dishwasher is concerned; it is a well-structured review of 84 peer-reviewed journal publications focusing on the dishwasher, accessed through Scopus and contacting researchers through ResearchGate, spanning the time period 1980–2021, originating in 21 countries (with Germany leading the pack, with 22% of the publications), and sourced from 63 different journals. Over a 16-year period between 1998 and 2014, both the energy use and water consumption of dishwashers decreased by well over 40%. Consumers in the USA, reportedly, are willing to pay up to 90% more for a higher-rated dishwasher. Interestingly, a publication from Germany states that manual dishwashing, if done in accordance with the Best Practice Tips (recommended by another German study), can have a 20% lower environmental footprint than automatic dishwashers.

Keywords: dishwasher/s; dishwashing; environment; hygiene; sustainability; sustainable production and consumption; techno-functional

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1. Introduction and Motivation

Dishwashing—be it manual or machine-enabled—is a frequent household (kitchen) task that needs to be carried out as a daily routine [1]. An automatic dishwasher, simply put, has 'the system function of cleaning crockery and cutlery in the larger totality of a system concerned with producing and consuming food' [2]. There is a higher probability of finding a machine—electromechanical, in other words—dishwasher in a modern-day urban household in the developed world, at the time of writing, compared to the turn of the millennium, two decades ago. It has evolved from its invention as a wooden machine containing a hand-cranked wheel in 1850, to a gas-powered contraption in 1911, to a freestanding equipment with permanent plumbing in 1920; and from 1950 onwards, quite phenomenally, to the highly advanced white good in application today [3]. Close to 80% of households in the USA [4]) and 44% of households in the EU [5] avail of the services of these appliances, which account for a small but not insignificant share of household material stocks, domestic water and energy usage, and thereby the wastewater loads on treatment plants. Machine dishwashers have not been able to make a conspicuous foray into cities of the developing world as yet—less than 10% in Asia and Latin America as of 2017, as reported in [6]—however, they are more commonly used in hotels and hospitals.

While affordability and a rise in the purchasing power of households will increase demand for dishwashers in the years to come, energy prices, environmental considerations, and water scarcity issues call for stricter norms and regulations, which in turn will lead to technical improvements in design and production. User awareness and behavioural changes—the social dimension reacting to triggers from the economic and environmental dimensions of sustainable development—are indispensable. This decade, in which industry, academia, government, and society need to work shoulder to shoulder to march steadily toward a clutch of sustainable development goals (SDGs, United Nations) set for the year 2030, may well be a bellwether for what humankind can expect for the remainder of the century.

Effective life-cycle management of machine dishwashers, with contributions from both the upstream producers and the downstream users—sustainable production and consumption, in other words—posit these appliances as contributors to a set of interrelated SDGs and targets thereof. Over the years, researchers have studied and analysed different aspects of machine dishwashers—techno-functional, social, environmental, economic, and politico-legal/regulatory (depicted in Figure 1), as well as the socio-environmental aspects of manual dishwashing. As we brace ourselves for the next nine years, in which giant strides (no longer baby steps) need to be taken in the march toward the SDGs, it is useful to obtain an overview of research which has been conducted heretofore in academic circles into these aspects.

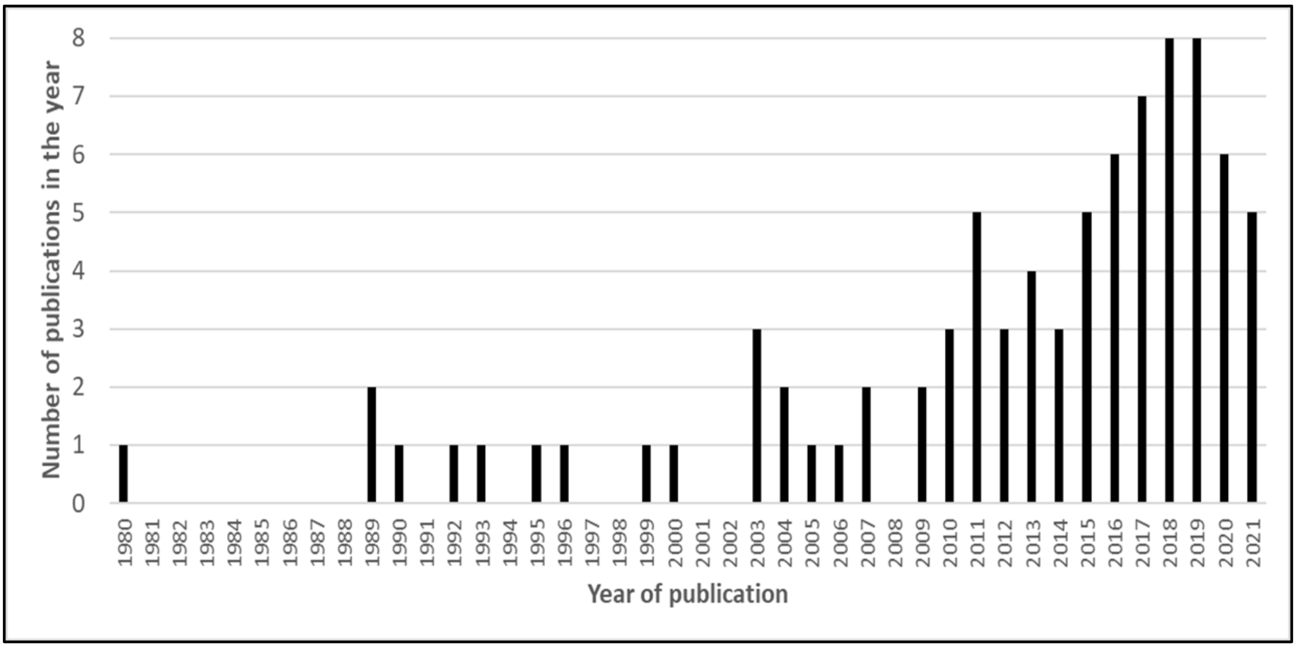

Figure 1. Temporal spread of the 84 publications reviewed.

The next Sections 2 and 2.1 present the motivation, research questions which the author intends to answer with the help of this review, and the review methodology in brief. It must be mentioned here that what follows is not a 'critical review' per se, but the findings from the literature are woven together to throw light on the aspects referred to in the previous paragraph. It is followed thereafter by a structured discussion (Section 3, with Sections 3.1–3.5; and Sections 3.2.1, 3.2.2, 3.4.1–3.4.3, 3.5.1 and 3.5.2) which throws light on the past and present, while also serving as a cauldron for ideas for developmental research in the years to come. The last Section 4 summarizes the contents of this review and recommends similar studies in the future, targeted at this journal.

2. Search Methodology

The end goal of this review, as mentioned in the Abstract, is to present the automatic dishwasher—almost ubiquitous and taken-for-granted in the western world these days—as a candidate for progressive research and sustainable development, resulting in its continued evolution. The author facilitates this by providing an overview of the different aspects of sustainability—techno-functional, social, environmental, economic, and politico-legal/regulatory, as well as the socio-environmental aspects of manual dishwashing—addressed by researchers thus far. It at once reinforces the importance of transdisciplinary research to ensure that improvements in one aspect do not undermine or thwart those in any of the others. Hereunder is a concise list of research questions, which the review throws light on:

1. Which countries have dominated research (number of publications being a loose proxy for dominance) in the different aspects of dishwashers?
2. How has the automatic dishwasher progressed over time, as far as energy efficiency, water-use efficiency, and material intensity are concerned?
3. What were/are some of the compelling reasons behind, and drivers of, a shift from manual dishwashing to automatic dishwashing? Likewise, what may stop someone from purchasing and using a dishwasher?
4. How can manufacturers ensure the most sustainable user behavior? What is lacking now in this regard?
5. Why have the health-related impacts of using an automatic dishwasher not been given much prominence?
6. How effective can legislations be in ensuring that the automatic dishwasher serves its purpose sustainably?

Only articles and reviews with the word 'dishwasher', 'dishwashers' or 'dishwashing' in their titles were sought on Scopus on the 1 November 2021. Scopus was chosen as it enjoys a reputation for being the most comprehensive database of peer-reviewed journal publications. This, admittedly, excludes many relevant publications, in which the above words may not have been used in the titles—those with a general focus on kitchen appliances/white goods in general, and do not adopt a niche focus on dishwashers. On this premise, the author makes a reasonable assumption that publications with a niche focus on dishwashers must have one of the three search words in their titles. Both household and commercial (restaurants and hospitals, for instance) dishwashers are included in the review.

2.1. Results of Literature Search

The oldest article in the list is from 1980, with 41 years separating it from the clutch of newest ones published in 2021. Exclusions were inevitable. All the articles which were accessible and downloadable for reading have been included. Some of those which could not be freely downloaded were obtained on request from the authors in question, via ResearchGate (four in number). Those which could not be obtained in this fashion (eight in number), were not included, as the author, instead of just relying on the abstracts, decided to adhere to the practice of reading articles in their entirety, some of them twice over, for clearer comprehension.

Further, the search uncovered papers belonging to the realms of art, philosophy, psychology, humanities, and aesthetic education, in which 'dishwasher' or 'dishwashing' were used in the title merely as a metaphor, or to connote the profession of washing dishes in restaurants and hospitals. These (15 in number), unarguably, also had to be excluded. This exercise ultimately left the author with 84 publications to read and review. All 84 were read over a period of 38 days.

Table A1 in the Appendix A lists the 84 articles, with country of origin, year of publication, and name of journal. The last column also provides aggregated data on the number of publications per year, over the 41-year period. Figures 1 and 2 depict the temporal and geographical spread of the 84 articles.

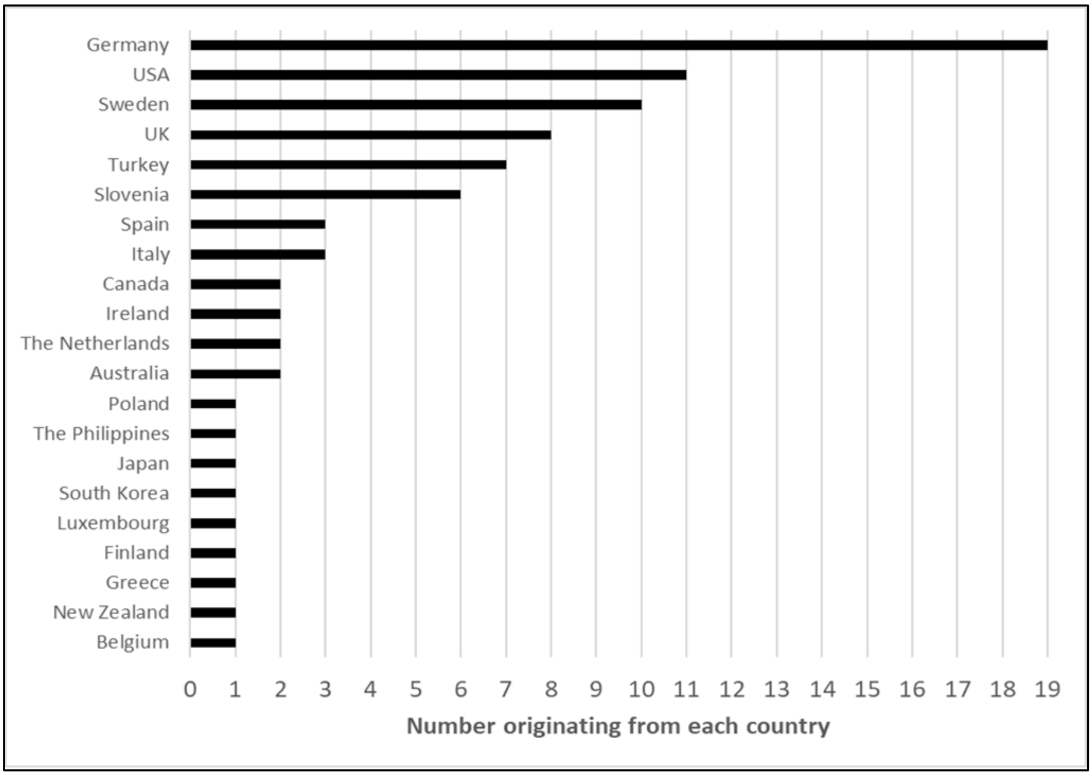

Figure 2. Geographical spread of the 84 publications reviewed (based on first author's affiliation).

Regulations related to energy labelling and eco-labelling, as well as the publication of the SDGs by the United Nations, have stimulated more research into the five aforenamed aspects of the automatic dishwasher. This is evident from the concentration of the publications on the right of Figure 1. Of the 21 countries in the fray, Germany leads the pack with 19 of the 84 (22%), followed by the USA (11) and Sweden (10). A continental split gives us 13 for North America, 65 for Europe, and 6 for Australasia. The spread over 63 different journals points to the multi-disciplinary nature of research, positing the dishwasher as an object of interest for researchers from different fields. The International Journal of Consumer Studies (all the seven publications from Germany) and Energy Efficiency are the top two journals in this long list, accounting for 14% of the 84 publications.

3. Discussion

The discussion based on the literature review done by the author is organised into five different aspects of importance, on the basis of the primary focus adopted by the authors of each paper (refer also to Table 1). While one primary focus can be identified for each publication, there may often be more than one secondary focus. The aspects, needless to say, are interrelated, and influence each other to different degrees (refer to Figure 3). This web of influence is iterative in nature, with the actions of the stakeholders—governments, producers along the value chain, consumers, energy suppliers, water utilities, waste management utilities, detergent manufacturers, etc.—triggering a need for change on a continuous basis. Consumer choices are influenced either by the initial cost of the machine, or by the life-cycle costs (for those who are more aware and also environment-friendly) (III–IV). The initial cost and thereby the life-cycle cost is determined by techno-functional developments wrought by the manufacturers (I–III), who in turn need to abide by top-down norms and regulations (I–II) and be aware of user expectations (IV–II). Life-cycle costs are also impacted by taxes levied on power producers (carbon tax) and wastewater treatment plants (levy on phosphorus emissions, for example) (I–III), which are eventually passed on to the consumers. Such taxation may influence user behaviour and motivate/impel them to be more responsible consumers (I–IV). The manner in which the users avail of the services of the dishwasher—time, temperature, detergent, frequency—has a direct link to the environmental impacts, ranging from global warming (non-renewable energy use) to possible eutrophication (inappropriate detergent usage) (IV–V). The state of the environment may stimulate the introduction of new or revised emission standards (V–I). Health and hygiene, directly related to the quality of the output from dishwashers, as well as the maintenance of the machines, are also very vital social aspects. It must be mentioned at this juncture that the identification of the foci was done entirely at the author's discretion. It is apt to embed this discussion within the SDG framework of the United Nations, as a motivation for understanding the dishwasher (and the process of washing dishes in general) as an enabler/driver/contributor to sustainable development. Relevant SDGs have been referred to in these sub-sections, and are also shown in Figure 1.

Table 1. Categorisation of the publications on the basis of primary focus and sub-foci.

Primary Focus	Sub-Focus	Publications	Total
Environmental	None	[7,8]	2
	Social	[4]	1
	Economic	[4]	1
	Techno-functional	[9]	1
Total with a primary environmental focus (4)			
Social	None	[2,10–33]	28
	Economic	[34,35]	2
	Environmental	[1,3,6,35,36]	5
Total with a primary social focus (34)			
Economic	None	[37]	1
	Social	[38]	1
	Politico-legal/regulatory	[38]	1
	Environmental	[38]	1
Total with a primary economic focus (2)			
Techno-functional	None	[39–56]	18
	Environmental	[57–65]	9
	Economic	[59,60,63]	3
	Social	[52,66–74]	12
	Politico-legal/regulatory	[67]	1
Total with a primary techno-functional focus (39)			
Politico-legal/regulatory	Techno-functional	[5,75]	2
	Social	[5,76–78]	4
	Environmental	[76,77]	2
	Economic	[76,77]	2
Total with a primary politico-legal/regulatory primary focus (5)			

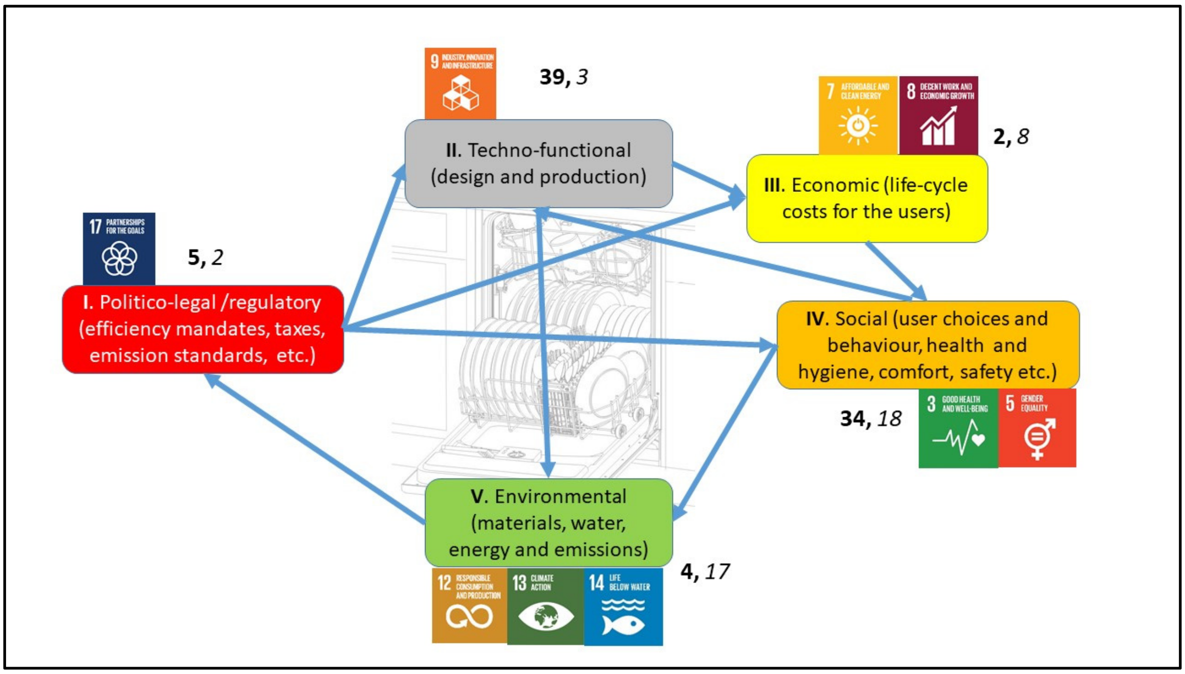

Figure 3. The web of influence among the aspects and the SDGs in question (The numbers in bold indicate the number of articles in which the aspect was the primary focus, while the numbers in italics indicate those in which the aspect was a sub-focus. The arrows have been referred to within parentheses in the text; the Roman numerals denote the origin (influencing aspect) and the destination (influenced aspect)).

3.1. Politico-Legal/Regulatory

SDG 17 (Partnership for the goals) can be named here, if one realises the importance of necessary, clear standards which do not mislead to come into play in the global marketplace. Top-down regulatory control which operates with a 'carrot-and-stick' approach, by adopting the fourfold strategy of gentle exhortation, incentives, levy of fines, and penalties, and imposing bans and sanctions [79], in that order of preference, is essential to ensure that bottom-up efforts to consume sustainably are able to move up and meet the top-down initiatives halfway for the optimally best, win–win outcomes. Dishwashing standards (such as EN50242, which came into force toward the end of the 1990s in Europe), the mandating of energy labels (in Europe, Regulation (EU) 2017/1369, which came into force in early 2019, replacing the pristine Directive 2010/30/EU, mandating the rescaling of the energy labels on an A–G scale, doing away with the A+, A++, and A+++ in the process) and the Ecodesign Regulation ((EC) 1016/2010), have been instrumental in triggering techno-functional research and developmental work on the upstream of the life cycle of the dishwasher [76].

From [75], one gets to know when the standby power usage of a dishwasher was also factored into the energy consumption reported to consumers in the USA. As reported in [57], the share of energy-efficient dishwashers in the functioning household stocks increased from 61% in 2011 to close to 95% in 2014, and one can only assume that this has increased further to encompass the entirety of the operating stock. However, as researchers such as [5,39] have pointed out, while the energy efficiency label of a dishwasher is based very specifically on the ECO program (with even the ambient temperature specified), users do not select this program all the time. One of the main reasons furnished is its relatively longer duration [76]. In [58], Persson and Rönnelid advocated a change in the labeling system to promote dishwashers using heat (recovered waste heat or solar heat) instead of electricity.

EU policy forced manufacturers to develop phosphate-free (P-free) detergents, and by 2018, the P-content of detergents per washing dose was strictly regulated to below 0.3 g [7]. While some countries have banned P-containing detergents outright, there are many laggards elsewhere in the world, which need to follow suit, sooner than later. Does a reduction in the P content of the influent at wastewater treatment plants (WWTPs), courtesy the use of P-free dishwasher detergents, manifest as a proportional reduction in the P content of the treated effluent which is discharged to the hydrosphere? Not necessarily, as found by [77]. It is possible that a ban on phosphate-containing detergents (a sustainability measure taken upstream), together with a tendency on the part of WWTPs to adhere to the same degree of P removal as before, may result in over-compliance, implying the aforementioned manifestation on the downstream. However, a rational decision on the part of some WWTPs may even be to decrease the degree of P removal after sensing a drop in P concentration in the influent. This would enable them to reduce treatment costs (benefits passed on to households), while still complying with the standards. On the other hand, WWTPs which do not need to abide by P emission standards will, without a doubt, register lower P concentrations in their effluent discharges, thanks entirely to the upstream measures. In [77], Cohen and Kaiser advocate a tax on P emissions that is high enough to make investments in upgrading treatment infrastructure economically feasible. The costs here, however, will be passed on to the households discharging wastewater.

3.2. Techno-Functional

Automatic dishwashers take tableware (dishes and cutlery, in other words) on a journey from 'dirty and soiled' to 'wet, de-soiled and very warm' to 'dry, visually-clean and at-room-temperature', by using electrical energy which gets converted to mechanical and thermal energy during the washing–drying cycle. It is an invention which blends together applied thermodynamics, fluid mechanics, and material sciences, and quite like all technological inventions, it has evolved over time, and will continue to, driven my market demands (including competition) and top-down regulations. SDG 9 (Industry, innovation, and infrastructure) can be named here, as technological innovations have had, and will continue to hold, the potential to drive progress on the path of sustainable development.

3.2.1. Design and Production

Tecchio et al. [40] and Johansson and Luttropp [9] emphasised design for disassembly and recyclability, and the need to ensure that dishwasher repair technicians have a stock of 'second-hand' spare parts (especially in cases where obsolescence affects the accessibility and availability thereof in the market), so that the equipment does not have to meet a premature end to their useful functional lifetimes. In the 1990s, when Computer-Aided Design (CAD) was entrenching itself in the industry, Asteasu and colleagues [41] discussed the pros and cons of tailor-making CAD systems for dishwasher design. Industrial designers have to stay attuned to customer requirements, and translate these into design requirements which are then input into the fabrication/assembly processes, which is a challenge. Users often make decisions based on imprecise and non-numerical information. Fuzzy logic is a handy tool to tide over this impasse. In [42], the authors processed images of clean and dirty dishes, while the fuzzy cognitive map-based quality function deployment approach was adopted by [43].

The average energy use per cycle (of the Eco program) of a dishwasher has, as illustrated as a time series in [39], dropped from a high of 1.43 kWh in 1998 to 0.942 kWh in 2014. Bengtsson and Berghel [44] referred to a V-ZUG Adora SL WP dishwasher equipped with a heat pump for heat recovery from greywater that reached 0.48 kWh/cycle. In 2003, as gathered from [75], a compact dishwasher, to be energy-compliant in the USA, had to have an energy rating of not less than 0.62 cycle/kWh—in other words, a total energy usage of not more than 1.61 kWh. Way back in 1977, a dishwasher used as much as 3.7 kWh per cycle. It is evident that there has been a conspicuous improvement in energy performance over the years.

In 2014, in Europe, dishwashers accounted for an electricity usage of 29.7 TWh, and a water consumption of 298 million m^3 [76]. A dishwasher accounts for a very small percentage of household electricity use—2% in the USA, according to [59], and 3.5% in Turkey, as reported in [57], but that is certainly not a deterrent to improving its energy efficiency by incorporating waste heat recovery sub-systems. A dishwasher is equipped with an electrical resistance heating element, which, as shown by [45], transfers heat to the machine interiors and the tableware primarily by radiation (up to 80%), and at red-hot surface temperatures approaching 1000 °C, the intense thermal radiation emanating therefrom can be detrimental to plastic tub materials. Electrical failures in the heating elements have, in the past, led to fires and damage in the USA, necessitating product recalls, as reported in [66]. Perhaps, this too was a motivating factor for replacing electricity with heat recovered from greywater, in addition to the environmental and economic drivers.

A fin-and-tube heat exchange tank recovering heat from the greywater streams leaving the dishwasher after the pre-washing, main washing, and first rinsing steps, and transferring the same to the corresponding successive freshwater inflow streams—main washing, first rinsing and second rinsing—can potentially truncate the annual energy footprint of the dishwasher by about 57 kWh, considering average Turkish frequencies of use [60]. A conference paper which has not been listed either in Table 1 or in the List of References of this article, originating from Chinese researchers, introduces a multi-functional, dual-refrigerant, air-source heat pump system (Coefficient of Performance greater than 3.2) that supplies hot water for washing, hot air for drying, very hot water for disinfection and cold air for rapid cooling, and accomplishes an 80% reduction in primary energy requirements. Though the payback period for such an investment has not been reported, environmentally, this would be a huge step forward, when one considers fossil fuel-heavy electricity mixes.

Bengtsson and Eikevik [61] evaluated three different refrigerants for use in dishwasher water-source heat pumps [46], and zeroed in on R600a (Iso-Butane), if a reduction in the greenhouse gas footprint were to be prioritised over accommodating a slightly larger compressor cylinder. While Bengtsson and Berghel [44], in one follow-up paper, introduced a closed dynamic drying system, in which the heat pump which cools water in a tank later aids the condensation of humid air in the drying step on its outer wall; in another paper [47], they tested the effect of different lengths of capillary tubes connecting the condensed refrigerator exiting the dishwasher to the evaporator on performance and compressor electricity usage. They concluded, among other things, that a higher drying start (and, therefore, rinsing end, too) temperature, longer drying cycle, and more ice in the tank providing cooling energy, can improve the drying performance of the dishwasher. This also proved to be slightly more energy-efficient compared to the open dynamic drying method adopted in [46]. Santori and colleagues [48] compared three desiccants—13X-zeoilte, microporous silica gel, and SAPO-34 zeolite—as adsorption–desorption media in an adsorbent bed heat loop exchanger, and decided in favour of silica gel, on account of its cheaper and easier commercial availability at that time, despite its slightly lower adsorption capacity vis-à-vis SAPO-34 zeolite. Pelletised 13X-zeolite was the adsorbent of choice in [62], the authors whereof demonstrated that a 24% reduction in energy use was possible, precisely the same percentage arrived at for the dishwasher equipped with a heat pump in [46]. However, heat exchangers, according to [57], trump heat pumps and adsorbent bed heat loop exchangers when it comes to cost, maintenance, simplicity, reliability, and compactness. There is a concurrence between [44,57] as far as spatial limitations are concerned, but aver that these can be overcome with design optimisation in the future.

While decreasing the need for electricity to heat the water by recovering heat from greywater is indeed good, how about replacing electricity altogether with solar energy, especially in instances where solar heat is already being used for interior heating, providing hot water for bathing, etc.? This can be done by increasing the collector surface area to capture more solar energy [58]. Here, we are thinking about not merely energy efficiency but 'renewable energy efficiency'—both a qualitative and quantitative improvement in the energy footprint. The authors referred to reported that, when pipe heat losses and the electrical energy for circulation are taken into consideration, solar heat-fed dishwashers may actually consume about 20% more energy (heat and electricity) than their electrical energy-heated counterparts, even though the electrical energy demand is reduced. In addition, the high temperatures reached in solar water heaters in countries such as Greece [10] 12 damage the elastic parts of the dishwasher input line. This therefore throws up another design challenge—redesigning parts with materials capable of withstanding these high temperatures.

The main purpose of a dishwasher, of course, is to separate the food particles, oil, etc., from the dishes, and transport the former with the greywater out of the drain. While Richter, J. [49] developed and tested a near-infra-red spectroscopic online tracking system for food particles separated from the dishes, Tang [80] identified the three short journeys the separated particles traverse along with water—dishes–tub, tub–sump, and sump–drain—and Perez-Mohedano and colleagues in [50], analysed water flow using positron emission tracking into five discrete stages—inside pump and spray arm, ejected stream, impact on obstructions, descent from point of impact over crockery, walls, and, finally, residence in the bulk water at the bottom before being drained out. In [80], Tang emphasised the importance of the inclinations of the coarse and fine filters in the sump, to optimise the particle-handling process. While the author recommends an inclination of between 5° and 10° for the coarse filter, he has shown that the fine filter must not be inclined at an angle greater than 77°, while the authors of [50,51] contributed to a better understanding of the effect of dishwasher dimensions, spray arm design, and crockery distribution on washing performance.

3.2.2. Use Phase

The output of dishwashers in hospitals is particularly critical, as nosocomial food-borne infections have to be avoided at all costs [81]. Noting that bacteria such as E. faecium are not easily exterminated by the high temperatures prevailing within the dishwasher during and after the rinse cycle, Ståhl Wernersson and co-authors in [78] stressed the need to ensure that dishwashers are able to provide a high degree of mechanical cleaning, which reportedly has a negative correlation to the yeast colonies detected in dishwashers [52]. Kerschgens and colleagues [82], in hygienic performance tests carried out with M. Luteus, found that higher washing temperatures were more successful in reducing viable cell count than higher rinsing temperatures.

Commercial establishments in some countries have to abide by some mandates enforced by health agencies, which for instance could be the prescribed limit of bacterial colonies per washed utensil (measured in Colony-Forming Units, or CFUs, per utensil). Thermal and/or chemical disinfection [67,81] thereby becomes mandatory in order to achieve a substantial reduction in CFUs per utensil, even though polyextremotolerance, if attained by the microbes, poses a hindrance to the success of such sanitisation routines. Though the authors of the said paper detected, to their surprise, that the use of chlorinated detergents seemed to be correlated with higher CFUs per utensil (over the permitted limit of 100), they are of the view that correlation does not necessarily imply causation in this case.

While on detergents, it must be mentioned that Brands and fellow researchers [68] managed to prove that, while it is a combination of three factors—time, temperature, and type of detergent—that determines the extent of microbial reduction, activated oxygen bleach (AOB) detergent (non-chlorinated) performed slightly better than its chlorinated counterpart. AOB was also shown to be effective against antibiotic-resistant species such as methicillin-resistant Staphylococcus Aureus [69]. As AOB is slower acting than chlorinated alternatives, a longer time and a higher temperature is usually needed to compensate for the slowness [68], though Rehberg and colleagues in [69] have stated that it has the ability to inactivate resistant bacteria even at lower temperatures. The chlorine in detergents, residual chlorine, and disinfection byproducts in the wash/rinse water tend to interact with soluble proteins in food particles on the dishes and form trihalomethanes, which are released into both the greywater and the atmosphere (from the dishwater headspace) [53]. Also found in the headspace are several volatile organic compounds (VOCs) [70], some of which, originating from food residues, are malodorous—organosulphur compounds, ketones, terpenes, aldehydes, alcohols, acids, pyrazines, lactones, and esters, among others—and Ontañón and colleagues [71] recommend a better solution to remove them to improve the quality of the indoor air, than the existent titanium dioxide bulb and ozone-producing unit.

Dentists need to sterilise their equipment regularly to avoid infecting their patients. O'Connor and Armstrong [72] compared the performance of the washer disinfectors which are commonly used in dental clinics with that of household dishwashers and found that the latter failed both the protein and the total viable microorganisms tests. Dishwashers do not operate at the high temperatures needed for effective disinfection, and commercial detergents are not compatible with medical/dental instruments. However, Ebner and colleagues in [73] came to the opposite conclusion about the suitability of dishwashers, in this context.

In a methodical energy-balancing experiment, which puts the thermodynamics of the process in perspective, Jeong and Lee [54] started off from the premise that all the energy input (electrical and mechanical, which was converted to heat within the dishwasher), is ultimately converted into heat losses—convection through the dishwater body in the greywater exiting the drain (which, as discussed earlier, can be recovered) and as latent heat for evaporation of water. During the cycle, which starts and ends at ambient room temperature, heat accumulated in the dishes and the dishwasher is released to one of these three outlet routes. The energy accumulated in the dishwasher and dishes in the rinsing step facilitates the evaporation of the water droplets on the dishes into the internally circulated air in the drying step.

3.3. Economic

While techno-functional improvements tend to push up the initial purchase price, users need to be aware of the life-cycle costs (or the so-called total ownership costs), which are greatly influenced by the operational and maintenance (repairs and part replacements, for instance) expenditure incurred, as well as the functional lifetime of the dishwasher. SDG 7 (Affordable and Clean Energy) and SDG 8 (Decent Work and Economic Growth) make dishwashers affordable for an increasing number of households in the world, which can be mentioned in this section.

If Turkish householders are happy with a payback period of 6.7 years for investing 52 USD more in a dishwasher with inbuilt heat recovery, the recommendation of Selimli and colleagues [60] referred to earlier, may very well also bring about environmental benefits. In a paper originating in Belgium [63], De Paepe and fellow researchers also arrived at a similar value for payback period much earlier, for a swirl-based heat recovery system—6.4 years vis-à-vis 13.2 years for a valve-based alterative. The latter, which was costlier, however, was shown to recover more heat energy (33.5% of the total requirement vis-à-vis 24%). Blum and Okwelum [59] are of the view that consumers often need to make a trade-off between the amounts of energy and water required—for either economic or environmental reasons or both—while considering a dishwasher's economic-technical (or techno-economic) efficiency; of course, this choice is determined almost entirely by the prevailing local conditions. While studies such as [11] indicated a growing emphasis among prospective buyers of dishwashers to consider energy-use and water-use efficiencies as important criteria to bring down the total cost of ownership, the authors of [10] observed that Greek households prioritise initial cost. In [40], Tecchio and colleagues reveal that consumers are willing to pay 30% more for more durable dishwashers and in [66], Law and co-authors observed willingness among consumers in the USA to pay up to 90% more for a higher-rated dishwasher. Boyano and Moons [76] estimate that if an automatic dishwasher were equipped with advanced technologies for energy saving (up to 50%)—increased program duration, fan for better air circulation, improved sensors, automatic door opening system, feedback mechanism, and a heat pump for heat recovery—the manufacturing cost would go up by about EUR 160, pushing up the retail price even more. Extending the operational lifetimes of products certainly has both economic and environmental benefits, which must be taken advantage of.

For those who would like to own a dishwasher but are deterred from owning one by the initial cost and hindered by space constraints, low-budget entry models and slim-line/table-top options may be attractive [1]. The global economy is a complex web of interactions, give-and-take, supply-and-demand, which leads to direct and indirect influences of changes effected in some sectors, on some or all to different degrees. In an interesting analysis of the macroeconomic effects of stricter EU energy efficiency regulations on household dishwashers, washing machines, and washer dryers on the economy of the European Union, Rocchi and fellow researchers [38] showed that, economically, there may be a net negative impact, with the sectors negatively impacted outweighing those benefitting by about EUR 2 billion. Obviously, the electricity and gas sector would take the biggest hit owing to a drop in energy usage by the three categories of white goods. However, a net increase in employment generation of 24,000 positions is predicted. On an individual household level, though, if the monetary value of the time spent washing dishes can be factored in, a machine dishwasher with a 10-year operational lifetime has an attractive payback period of less than a year, according to [4].

In a paper which is now 16 years-old, Kochan [37] discussed the foray of robotics into dishwasher manufacturing, using Bosch and Siemens Hausgerate (BSH) as a case study. Dedicated automation, machine vision, and robotics, alongside quality assurance techniques, since then, have evidently grown in leaps and bounds to improve quality and increase output from plants around the world. Quite like automatic dishwashers relieve human beings of the strenuous and 'back-breaking' dish-washing task, robots, which guarantee a very attractive payback period, have taken over demanding and hazardous unit operations on the shopfloor.

3.4. Social

The end user of a dishwasher expects benefits in terms of health and hygiene, comfort and convenience (time saved and manual effort avoided), and safety (from injuries) when he/she invests in a machine dishwasher to supplant manual labour in the kitchen. One finds a relation to SDG 3 (Good health and well-being), and also, indirectly, to SDG 5 (Gender Equality), as in the developing world, into which dishwashers have not yet made as wide a foray as in the developed world, manual dishwashing is often done by the women in households or by female maids who are hired for the purpose. It is certainly not entirely uncommon in the developed world, as observed for Greece [10].

3.4.1. Health, Safety, and Hygiene

Pathogens lurk in the water used for dishwashing, as well as in the biodegradable organic food residues on the dishes [12–16,52,78], some of which may get trapped inside the dishwasher for long times, forming in the process, substrates for saprobial growth. The repeatedly oxidative, moist, alkaline, and high-temperature environs prevailing within a dishwasher are conducive for a phylogenetically diverse mycobacterial–algal biofilm formation on rubber seals [17–19,52,83], and the development of antibiotic resistance among bacteria [69], with new dishwashers, operated frequently with moderately hard water and low temperatures, emerging as the best 'harbours' of such active biofilms, as per a study done in [15]. Frequent operation, evidently, ensures a regular supply of organic matter to the microbial colonies and higher humidity [78]. While Zupančič and colleagues in [13] conclusively discovered that tap water is the predominant vector for fungi, as they were found even in kitchens which did not have dishwashers. The food residues on plates are held culpable for contaminating the dishwasher and the wastewater, and thereby also dishes, with pathogenic bacteria by [15]. Among fungi, the Exophiala taxon, which has the ability to assimilate detergents, breaks down aromatic hydrocarbons and resists antibiotics, dominated in dishwasher samples tested from around the world by [13,17], though, as Koren and colleagues [16] have noted, in general, the fungal biomes differ in composition and richness. While these are issues certainly to be taken seriously in hospitals [20,81], in homes where immunosuppressed patients dwell, the dishwasher can be a very likely cause of dangerous fungal and/or bacterial infections, primarily affecting the lungs.

Injuries sustained in the kitchen during loading and unloading of dishwashers are not uncommon [21], while cases of scalding experienced by infants due to contact with hot dishwasher effluent [22], mucous membrane damage, and reactive airways dysfunction due to inhalation of detergent powder [23–26] and accidental ingestion of dishwasher detergent by children [24,26–29] have also been reported. Manufacturers have responded to these risks by incorporating safe operating practices in manuals, but as reported in many studies, not all users are responsible enough to read, understand, and follow the instructions religiously.

3.4.2. Comfort, Convenience, Consumer Experience, and Behaviour

Mechanisation and automation, in general, are meant to add comfort to human existence, and save time and energy (at the expense of money spent on mechanising and automating), for either leisure activities or financially rewarding ones. In other words, the 'opportunity cost of time which would otherwise be spent on doing manually what can be mechanised' is not incurred. Modern man seeks 'better quality of greater quantities at higher speed' in this faster-paced world.

Richter [11], on the strength of findings from international surveys, opined that general tips and hints may not be as effective as country-specific campaigns. One ought to think about the 'best-possible' for any country or region, after a thorough understanding of a host of socio-cultural factors. In [30], Richter referred to unsustainable dishwashing behaviour observed in Italy and Sweden resulting in additional water use of between 11 and 20 L per cycle. Also pointed out by this author is the fact that if the dishwasher is always operated at full load (or very near full load), the total number of cycles per household per year, can be decreased by 10%. However, if one needs to wait for the machine to be fully loaded, with soiled, unwashed dishes inside the dishwasher, does not that give rise to conducive conditions for unhindered microbial growth, before the cycle is started? Persson [55] also referred to a similar problem associated with stagnant hot water in heat exchangers which are installed to replace electricity with heat energy from boilers or solar heat collectors. Changes are often fraught with compromises and problem shifting, and the keyword is always 'optimisation'.

Microbial growth also contributes to a build-up of bad odour in the headspace of the dishwasher, as observed by [71], authors whereof detected 'garlic, metallic, unpleasant' odour caused by dimethyltrisulphide and 'garbage, fart' odour caused by methanethiol/ dimethyltrisulphide most often in their experiments. While Olson and Corsi [53] focused on trihalomethanes in the headspace, Reed and fellow researchers [70] discussed the mass transfer of VOCs from wash water to headspace air to the ambient atmosphere, and advised users to refrain from opening the dishwasher door immediately after the end of the cycle, to obviate exposure to hot aerosols, and 'puffs' of elevated concentrations of VOCs (some of which may be hazardous to health). Talking of tips and hints, load shifting is commonly practiced in many households and applies to the use of dishwashers too. However, the reasons behind using the 'delay start' function to time the dishwashing process, are quite varied, as determined by [34] in a survey conducted within Europe. They range from taking advantage of cheaper electricity tariffs (over 75% of French respondents) to simple convenience (25% of all respondents), to taking advantage of higher water pressure (a very small percentage). Interestingly, there were few who were not aware of this function, and some who, irrespective of whether they were aware or not, did not want to use it. Here is where a small but noticeable difference in individual cost of ownership can be engineered, if everyone were to emulate the 75% of the French respondents in the survey. The delay start function may be easy to miss, but it is alarming that, in another survey [6], there were households which were not aware that their dishwashers had an inbuilt ECO program. Load shifting, as part of demand management in households, enables more wind energy to be utilised in Irish households by flexing the timing of use of the dishwashers [35], instead of necessitating curtailments in generation or investments in energy storage systems.

Life-cycle management of a product entails monitoring (M2M or machine-to-machine communication, nowadays) and closely engaging with the consumers on a regular basis. This is extremely vital in a competitive global marketplace, in which firms can lose their disgruntled clientele quite easily and their brand reputations can be badly hit by negative online user reviews. Information about safety defects (serious) and performance defects (non-serious) of dishwashers, as described by [66], are vital inputs to manufacturers, primarily, and also to property owners and engineers. These can be gleaned both proactively using text classification tools on reviews submitted online to analyse the sentiments of end users, as well as gathered from consumer surveys and complaints registered with the suppliers. In an offbeat article of user innovation in function, with the dishwasher as an example, Cardinale and Runde [2] refer to how reflection, aided by serendipity and chance, led to the discovery of the thitherto-unharnessed function of an automatic dishwasher—low-temperature cooking. As the dishwasher is, after all, a component of the totality of a system concerned with producing and consuming food, it can also 'multi-task' by providing its ambient heat for cooking functions.

Noise (pollution), according to [74], is a subjective socio-environmental impact category, causing annoyance (an endpoint effect, defined by the authors). Annoyance experienced by users of dishwashers is correlated positively to loudness and roughness, two psychoacoustic parameters of emitted noise from the appliance. Abatement of this noise—a function of type of spray arm, rotational speed of the inlet and drainage pump, amount of water used, and the temperature of the tub—must not be neglected as a design criterion by manufacturers, according to the authors. It may very well turn out to be a decisive factor when a user makes his/her selection.

3.4.3. Manual Alternative or Complement

The entire process of washing dishes can be done manually, as it is done by and large in the developing world countries into which the automatic dishwasher has not made a conspicuous foray as yet. Lower back pain experienced by some manual dishwashers—the incidence is obviously quite high in the developing world—may well be one of the reasons motivating the purchase of an automatic dishwasher in these countries in the future. Even when a dishwasher is employed, there is human effort and time involved in pre-rinsing, loading, and unloading, complementing the machine in the process, as well as resorting to washing some types of tableware manually all the time [30]. The degree of human involvement may differ widely, but the task of dishwashing is, and continues to be, teamwork involving both man and machine [11], with manual washing undertaken by dishwasher owners to prevent breakage of fragile crockery and ensure cleanliness, and when larger-sized tableware does not fit into the dishwasher or there are very few washables to be handled [31].

Richter [30] observed that the percentage of dishes pre-rinsed before loading was as low as 4% in Germany, and as high as 42% in Italy, a practice related perhaps to force of habit, ingrained by observing parental behaviour from childhood days [84], for instance, for East European test participants and by [10] for Greek households, habituated to running-tap manual washing instead of using the soak-in-sink method), or an empirically derived lack of complete trust in the ability of the dishwasher to render good-quality output, irrespective of the degree of soiling of the load of dishes [3]. However, if pre-rinsing is deemed to be important, the dishwasher's 'rinse/rinse and hold' option which could be taken advantage of, and the purpose served with a much lower water footprint too [30]. Pre-rinsing of dishes by households owning dishwashers traces its origin back to the days of the oil crisis, which gripped the whole world, particularly the USA, where consumers lowered the temperature setting of their water heaters and pre-rinsed instead, with manual effort compensating for the lowered thermal input [3].

The Best Practice Tips (BPTs) propounded for manual dishwashing in [36] may not be able to beat an automatic dishwasher in terms of water-use and energy-use efficiencies, and output quality, though Porras and colleagues [4] believe that if the best practices are followed diligently, manual dishwashing may be able to reduce GHG emissions by 20% vis-à-vis automatic dishwashers. Participants in a UK survey [32] who were of the view that washing dishes manually saves resources were obviously misinformed, and most likely would benefit from the right information thereafter. However, in households which do not own a dishwasher and which do not intend to purchase one (for economic or space-related reasons or in support of a minimalistic lifestyle [1]), the BPTs are highly recommended. This is all the more advisable in developing countries which encounter water scarcity [6]. Fuss and colleagues [36] encountered some respondents who labelled these tips as 'old-fashioned', without realising that old-fashioned is often simple and, at times, the most effective solutions are the simplest. At the juncture we are poised at currently, it is advisable to learn from the past, even from antiquity, if need be.

The output of manual dishwashing—represented as dS (change in the soiling of the dishes)—is a complex function of time spent, water used, energy consumed (hot water), and type and quantity of detergent used. The time here, in turn, is a proxy for the manual scrubbing effort to remove the particles from the soiled dishes. In keeping with the Sinner circle, and quite analogous to the replicability of labour with capital or vice versa to get the same output from industry, users may decrease one of the inputs and compensate for the same by an increase in one or more of the other three. Less time would entail larger volumes of hotter water and perhaps more of a high-quality detergent. Less water would entail its requirement at a higher temperature and more time spent with manual input. Gillessen and co-authors [84] observed that even if 'dS' was changed, test participants, in general, did not seem to change the input-mix conspicuously (save the German participants, who used a lot more time when the dS was increased). In many countries, the factor 'energy' is not available [6], and washing is often done with only room-temperature water, necessitating greater inputs of time and, to some extent, detergents and water.

3.5. Environmental

Along the life cycle of any product—be it short-lived or durable—it interacts with the environmental media—land/soil, water, and air—by using them as direct/indirect sources for resources and sinks for emissions. The dishwasher or, for that matter, the task of dishwashing in general, if one considers the manual alternative to the machine, is no exception. Improvements in resource efficiency thanks to techno-functional upgrades, bring down the operational expenses in the life-cycle cost of a dishwasher, and at the same time, truncate its life-cycle environmental footprint. A tight relationship is at once found to the SDGs 12 (Responsible Consumption and Production, which happens to be the focus of this journal), 13 (Climate Action), and 14 (Life below Water).

3.5.1. Water and Wastewater

The annual water demand for automatic dishwashing per household per year is a small fraction of the total annual household water consumption. Thanks to technological improvements in the contraption, the water use per cycle (measured for the ECO program) has decreased from 19.14 L in 1998 to 10.34 L in 2014 [39]). Blum and Okwelum [59] reported that this represents approximately 10% of daily per-capita household water consumption. The stream of 'greywater' leaving the dishwasher (loaded with organics—carbohydrates, proteins, and fats—scoured out of dirty dishes, and chemicals from the detergents used) also adds to the wastewater load of the WWTPs. In the absence of collection and treatment, the dishwasher can be looked upon as a polluter of water bodies, contributing to eutrophication. The volume of the grey wastewater stream referred to generally increases significantly when dishes are washed manually (by 100% or more, as reported in [4]), as it is unlikely that the BPTs recommended by [36] are religiously and consistently adopted by manual dishwashers. It is an ironic double blow to the developing countries with low penetration rates for automatic dishwashers [6], which are plagued by water scarcity. The extremities of the percentage of dishes pre-rinsed, recorded by [29], referred to earlier (in Section 3.4.3), correspond to surplus per-cycle water use of 3 L (Germany) and 20 L (Italy) respectively. If heat can be recovered from greywater streams (Section 3.2.1), can the wastewater itself not be treated, upcycled, and recirculated for use in subsequent cycles? For this purpose, Congestri and colleagues [64] developed and tested a bio-filter harbouring a synergistic consortium—photosynthetic cyanobacteria releasing oxygen for uptake by aerobic heterotrophs in the filter, which in turn provide carbon dioxide to the former. While the uncontrolled biofilms with pathogenic mycobacterial colonies (Section 3.4.1) are undesirable, 'engineered' ones cultivated for bio-remediation of wastewater—in this case, resulting in an appreciable reduction in the nitrogen and phosphorus load—are extremely useful agents in a circular bio-economy [85].

Benzotriazoles and tolytriazoles, as reported by [33,86], are not easily biodegraded, nor are they completely separated out of the wastewater by mechanical or chemical means or UV radiation. These are ingredients of detergents, serving as silver-polishing and protection agents, and over 30% of what goes into the dishwasher by way of the tablets, is transferred to the hydrosphere receiving treated wastewater. Being aromatic and non-biodegradable compounds, these are pollutants of concern, and source control at the production stage ought to be practised, as advised by [86]. Janna and fellow researchers [33] deemed them to be potentially carcinogenic, and wrote in favour of the precautionary principle to be adopted. Source control, in fact, has resulted in a conspicuous decrease in the P content of detergents in Europe and some other developed countries. It must be pointed out that, globally, 153,000 tonnes of phosphorus contained in dishwasher detergents ended up partly in WWTPs or often directly untreated in water bodies in 2010 [7], accounting for about 14% on average of the phosphorus in the influent [77]. One, however, can also take comfort from the fact that hand-in-hand with source control, the average degree of P removal at WWTPs in the developed world, at least, has also increased significantly over time. Moreover, it is the developed world which accounts for the lion's share of dishwater detergent use to date.

While algal blooms in eutrophic freshwater bodies, have stimulated the introduction and the gradual proliferation of P-free detergents, at least in some western countries, Igos and colleagues [87] remarked that eco-labelled detergents do not present a 'net advantage over the phosphate-free alternative'. In a paper in which 14 ingredients of detergents were characterised for their toxicity potentials (benzotriazole and tolytriazole were not among them), sodium percarbonate was shown to contribute to 40% or more of the life-cycle freshwater ecotoxicity potential of phosphate-based, phosphate-free, and eco-labelled detergents produced, sold, and used in Germany, France, and the UK [87]. Hard/moderately hard water used for washing and rinsing increases the possibility of calcite/aragonite scaling on the inner surfaces of dishwashers. The most common anti-scalants used to date are phosphonate salts. If detergents have to become increasingly phosphate-free in the years to come, without any compromise in their functionality, these phosphonate salts will have to be substituted. Hong and colleagues [65] have hit upon a duo—cis-cyclohexane-1,2,3,4,5,6-hexacarboxylic acid and cis,cis,cis,cis-cyclopentane-1,2,3,4-tetracarboxylic acid—which can contribute to a further reduction in the P content of detergents in the years to come. Over time, more advanced detergents may perhaps enable effective dishwashing at much lower temperatures, with concomitant economic and environmental advantages [58].

Greywater effluent from the dishwasher is usually oily, and to date, alum is resorted to separate the oily matter by demulsification–coagulation–flocculation–settling. The dosage of coagulant can be considerably reduced without worsening the degree of separation, if cationic polymers—poly (dimethylamine-co-epichlorohydrin)—can be used in isolation or in combination with a much lower quantity of alum; that is, dematerialisation and trans-materialisation at the same time offer environmental benefits [8].

3.5.2. Energy and Materials

A dishwasher of any brand, as mentioned in [9], consists of about 40–50 parts, excluding the fasteners. While reducing the number of parts, when possible, is a good design approach; reducing weight is another. Better crashworthiness can be imparted to a dishwasher, according to [56], by reducing the mass of the dogplate and bottom foam by 2.3% and 21.5%, respectively. Over 25% of a dishwasher's mass, as gathered from the Bill of Materials presented in [4], is plastics, encompassing a whole range of them. What happens to them at the end of the operational lifetime of a dishwasher is very vital; one, of course, can safely assume that a very small percentage globally would be recycled or even incinerated for energy recovery. The steel, zinc, aluminium, and copper which account for over 50% of the mass, provide a small potential stream of secondary metals for the economy. Here, it must be mentioned that reuse of disassembled modular components as spare parts, wherever and whenever possible, must be encouraged [40], contributing to a circular economy which is a sine qua non for sustainable development [85].

Turkish electricity is fossil-heavy, and thereby the heat recovery option discussed in [60] must be considered not merely for its life-cycle economic benefits (which seem meagre), but also for the fact that the reduction in electricity use for heating the water (for washing and rinsing) also brings down the greenhouse gas footprint of the equipment by about 22 kg of CO_2e per year. Multiplying this by the potential number of households which may consider this favourable, a maximum of 8 million [57] will register a large decrease in GHG emissions—over 200 kt per year. A similar optimistic scenario for the EU-28 countries in the year 2030 is presented in [76]—a 670 kt reduction in GHG emissions, if the revised Ecodesign and Energy Label regulations (Section 3.1) are effective in bringing about the desired changes.

4. Conclusions

Only the terms 'dishwasher', 'dishwashers', and 'dishwashing' were used to search for published journal articles. The author would not wish to label this as a weakness or a limitation, but rather as an effort to focus on the most relevant articles with a niche focus on dishwashers. The aspects identified and the structuring of the discussion on the basis of the same are useful, novel contributions of this article. The identification of the SDGs associated with each of the aspects, is in keeping with the current focus among governments, industries, and researchers to collaborate and cooperate in the journey towards achieving the targets set by the United Nations. It is entirely by the author's discretion that the primary focus and the sub-focus/foci have been identified and tabulated in Table 1.

The author devised a set of research questions at the outset. The review has enabled him to answer the same satisfactorily. The steady progress in water-use efficiency and energy efficiency has resulted in the automatic dishwasher advancing as an environment-friendly contraption. However, researchers have warned against the problem shifting that may occur if water and energy are prioritised over the use of materials (or the so-called MIPS, material intensity per service). Legislation, if free of exploitable loopholes, have been shown to be effective in ensuring the desired progress towards sustainability. M2M technologies will go a long way to strengthen the manufacturer–consumer relationship and enable the manufacturers to 'stitch in time to save nine'. It is a paradox, indeed, that a contraption meant to promote hygiene may have adverse health impacts. However, this knowledge, courtesy researchers in the recent past, has been an eye-opener for designers and manufacturers, as well as users. A narrow focus on environmental footprints, to the detriment of health and well-being, has to be avoided, as researchers [13] have raised the following question—are green technologies, biodegradable detergents, and reduced energy usage resulting in lower temperatures silently turning water- and energy-using equipment such as dishwashers into breeding grounds for opportunistic and extremely resilient (antibiotic-resistant) pathogens?

Prima facie, shifting from manual dishwashing to automatic dishwashing seems to be a must, at least for modern-day urbanites, though the author gleaned good-enough reasons from some of the publications to maintain the status quo of washing dishes manually.

Just as source control and end of pipe must go hand-in-hand, and neither can be dispensed with, design for sustainability and responsible end user behaviour must co-exist. Sustainability is all about a fine balance, a 'marriage' between the upstream producers and the downstream consumers, if one may write thus. Automatic dishwashers have gradually entrenched themselves firmly, at least in the developed world, over the last 70 years. During this period of time, technological developments have contributed to making the contraption 'smarter' and 'more efficient', and the expectations of consumers have progressively been satisfied. However, like all other resource-consuming gadgets, which have added to comfort and convenience in modern-day households, the present and the future of dishwashers, just like their past, will be influenced by regulatory, techno-functional, economic, social, and environmental aspects, with conflicts to handle, trade-offs to make, and synergies to harness.

Thermodynamics, fluid mechanics, production engineering and materials science apart, microbiology, behavioural psychology, microeconomics and macroeconomics, and, of late, sustainable production and consumption, intersect to make the dishwasher a perfect candidate for multidisciplinary research. This candidature was what motivated the author to embark on this structured review of scientific, peer-reviewed journal publications. This paper, which the author would like to posit as the first of its kind, may also hopefully inspire a similar study of contraptions, devices, and equipment (white goods or otherwise) in the anthroposphere.

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Abbreviations

AOB	Activated Oxygen Bleach
BPT	Best Practice Tips
BSH	Bosch and Siemens Hausgeräte
CFU	Colony-Forming Units
EC	European Commission
EN	European Norm
GHG	Greenhouse Gas/es
SAPO	Silicoaluminophosphate
SDG/s	Sustainable Development Goal/s
UV	Ultraviolet
VOC	Volatile Organic Compound/s
WWTP	Wastewater Treatment Plant/s

Appendix A

Table A1. Publications sorted primarily by year of publication, and secondarily by first author surname and country of origin.

Number	Publication	Journal	Year	Country of Origin (Based on the First Author's Designation)	Number per Year
1	Jeppsson and Ejnell (1980)	Lakartidningen	1980	Sweden	1 (1980)
2	Kynaston et al. (1989)	Medical Journal of Australia	1989	Australia	2 (1989)
3	McDonald et al. (1989)	IEEE Transactions on Industry Applications	1989	USA	
4	Madarikan et al. (1990)	British Journal of Clinical Practice	1990	UK	1 (1990)
5	Asteasu et al. (1992)	Computers and Graphics	1992	Turkey	1 (1992)
6	Sheridan et al. (1993)	Pediatrics	1993	USA	1 (1993)
7	Cowan et al. (1995)	Journal of Hospital Infection	1995	UK	1 (1995)
8	Cornish et al. (1996)	Australian and New Zealand Journal of Public Health	1996	Australia	1 (1996)
9	Howard-Reed et al. (1999)	Environmental Science and Technology	1999	USA	1 (1999)
10	Ebner, W. et al. (2000)	Journal of Hospital Infection	2000	Germany	1 (2000)
11	Castro (2003)	Appliances	2003	USA	3 (2003)
12	De Paepe et al. (2033)	Applied Thermal Engineering	2003	Belgium	
13	Emmel et al. (2003)	Journal of Extension	2003	USA	
14	Olson and Corsi (2004)	Journal of Exposure Analysis and Environmental Epidemiology	2004	USA	2 (2004)
15	Ståhl Wernersson et al. (2004)	Journal of Hospital Infection	2004	Sweden	

Table A1. *Cont.*

Number	Publication	Journal	Year	Country of Origin (Based on the First Author's Designation)	Number per Year
16	Kochan (2005)	Industrial Robot: An International Journal	2005	Germany	1 (2005)
17	Bertinelli et al. (2006)	Journal of Paediatrics and Child Health	2006	New Zealand	1 (2006)
18	Persson (2007)	Applied Thermal Engineering	2007	Sweden	2 (2007)
19	Persson and Rönnelid (2007)	Applied Thermal Engineering	2007	Sweden	
20	Johansson and Luttropp (2009)	Journal of Cleaner Production	2009	Sweden	2 (2009)
21	Stamminger and Streichardt (2009)	SOFW-Journal	2009	Germany	
22	Berkholz et al. (2010)	International Journal of Consumer Studies	2010	Germany	3 (2010)
23	De Hoog (2010)	Persoonia: Molecular Phylogeny and Evolution of Fungi	2010	The Netherlands	
24	Richter, C.P. (2010)	International Journal of Consumer Studies	2010	Germany	
25	Fuss et al. (2011)	International Journal of Consumer Studies	2011	Germany	5 (2011)
26	Hauer and Fischer (2011)	Chemie Ingenieur Technik	2011	Germany	
27	Janna et al. (2011)	Environmental Science and Technology	2011	UK	
28	Richter, C.P. (2011)	International Journal of Consumer Studies	2011	Germany	
29	Zalar et al. (2011)	Fungal Biology	2011	Slovenia	
30	Abeliotis et al. (2012)	Resources, Conservation and Recycling	2012	Greece	3 (2012)
31	Finn et al. (2012)	Applied Energy	2012	Ireland	
32	Hannu et al. (2012)	Canadian Respiratory Journal	2012	Finland	
33	Döğen et al. (2013)	Medical Mycology	2013	Turkey	4 (2013)
34	Gillessen et al. (2013)	International Journal of Consumer Studies	2013	Germany	
35	Santori et al. (2013)	Energy	2013	Italy	
36	Vetter and Lorenz (2013)	Environmental Scientific and Pollution Research	2013	Germany	
37	Igos et al. (2014)	Chemosphere	2014	Luxembourg	3 (2014)
38	Jeong and Lee (2014)	Korean Journal of Chemical Engineering	2014	South Korea	
39	O'Connor and Armstrong (2014)	Journal of the Irish Dental Association	2014	Ireland	
40	Bengtsson et al. (2015)	International Journal of Refrigeration	2015	Sweden	5 (2015)
41	Koren et al. (2015)	Acta Agriculturae Slovenica	2015	Slovenia	
42	Muhsen and Khadim (2015)	International Journal of Injury Control and Safety Promotion	2015	UK	
43	Pérez-Mohedano et al. (2015)	Chemical Engineering Journal	2015	UK	
44	Sahai et al. (2015)	Food Protection Trends	2015	Canada	
45	Bengtsson and Berghel (2016)	International Journal of Refrigeration	2016	Sweden	6 (2016)
46	Bengtsson and Eikevik (2016)	Applied Thermal Engineering	2016	Sweden	
47	Davis et al. (2016)	Pediatrics	2016	USA	
48	Gümral et al. (2016)	Fungal Diversity	2016	Turkey	
49	Kerschgens et al. (2016)	Tenside, Surfactants, Detergents	2016	Germany	
50	Zupančič et al. (2016)	PLoS ONE	2016	Slovenia	
51	Bengtsson and Berghel (2017)	Energy Efficiency	2017	Sweden	7 (2017)
52	Cohen and Kaiser (2017)	Journal of Public Economics	2017	USA	
53	Law et al. (2017)	Expert Systems with Applications	2017	USA	
54	Mülcoğlu et al. (2017)	Structural and Multidisciplinary Optimisation	2017	Turkey	
55	Pérez-Mohedano et al. (2017)	Journal of Food Engineering	2017	UK	
56	Rehberg et al. (2017)	Journal of Applied Microbiology	2017	Germany	
57	Stamminger and Schmitz (2017)	International Journal of Consumer Studies	2017	Germany	
58	Blum and Okwelum (2018)	Energy Efficiency	2018	USA	8 (2018)
59	Hong et al. (2018)	Crystal Growth and Design	2018	UK	
60	Ontañón et al. (2018)	Flavour and Fragrances Journal	2018	Spain	
61	Raghupati et al. (2018)	Applied and Environmental Microbiology	2018	Slovenia	
62	Van Puijenbroek et al. (2016)	Data In Brief	2018	The Netherlands	
63	Wu et al. (2018)	Separation and Purification Technology	2018	Canada	
64	Yoshida et al. (2018)	American Journal of Infection Control	2018	Japan	
65	Zupančič et al. (2019)	Frontiers in microbiology	2018	Slovenia	
66	Austria et al. (2019)	International Journal of Scientific and Technology Research	2019	The Philippines	8 (2019)
67	Belke et al. (2019)	International Journal of Consumer Studies	2019	Germany	
68	Efe (2019)	Applied Soft Computing Journal	2019	Turkey	
69	Rocchi et al. (2019)	Energies	2019	Spain	
70	Selimli et al. (2019)	Sustainable Energy Technologies and Assessments	2019	Turkey	
71	Stamminger et al. (2019)	Energy Efficiency	2019	Germany	
72	Tecchio et al. (2019)	Journal of Cleaner Production	2019	Italy	
73	Zupančič et al. (2018)	BMC Microbiology	2019	Slovenia	
74	Boyano and Moons (2020)	Energy Efficiency	2020	Spain	6 (2020)
75	Brands et al. (2020)	Journal of Applied Microbiology	2020	Germany	
76	Brunzell and Renström (2020)	Energy Efficiency	2020	Sweden	
77	Congestri et al. (2020)	Water Science and Technology	2020	Italy	
78	Porras et al. (2020)	Environmental Research Communications	2020	USA	
79	Stamminger (2020)	Tenside, Surfactants, Detergents	2020	Germany	
80	Atamer and Ercan Altinsoy (2021)	Applied Acoustics	2021	Germany	5 (2021)
81	Cardinale and Runde (2003)	Cambridge Journal of Economics	2021	UK	
82	Kulesza et al. (2021)	Pathogens	2021	Poland	
83	Richter, J. et al. (2021)	Journal of Near Infrared Spectroscopy	2021	Germany	
84	Selimli and Abajja (2021)	Water Environment Research	2021	Turkey	

References

1. Stamminger, R.; Schmitz, A.; Hook, I. Why consumers in Europe do not use energy-efficient automatic dishwashers to clean their dishes? *Energy Effic.* **2019**, *12*, 567–583. [CrossRef]
2. Cardinale, I.; Runde, J. From dishwashing to dishwasher cooking: On social positioning and how users are drawn towards alternative uses of existing technology. *Camb. J. Econ.* **2021**, *45*, 613–630. [CrossRef]
3. Emmel, J.M.; Parrott, K.; Beamish, J. Dishwashing and water conservation: An opportunity for environmental education. *J. Ext.* **2003**, *41*, 1R1B3.
4. Porras, G.Y.; Keoleian, G.A.; Lewis, G.M.; Seeba, N. A guide to household manual and machine dishwashing through a life-cycle perspective. *Environ. Res. Commun.* **2020**, *2*, 021004. [CrossRef]
5. Brunzell, L.; Renström, R. Recommendations for revising the energy label system for dishwashers: Supporting sustainable development and usage through the interaction of energy labels, technical improvements and consumer behaviour. *Energy Effic.* **2020**, *13*, 145–155. [CrossRef]
6. Belke, L.; Maitra, W.; Nijhuis, B.; Presti, C.; Stamminger, R. Global consumer study to identify water wastage in the usage of automatic dishwashers. *Int. J. Consum. Stud.* **2019**, *43*, 471–479. [CrossRef]
7. Van Puijenbroek, P.J.T.M.; Beusen, A.H.W.; Bouwman, A.F. Datasets of the phosphorus content in laundry and dishwasher detergents. *Data Brief* **2018**, *21*, 2284–2289. [CrossRef]
8. Wu, W.; Palmarin, M.J.; Young, S. Poly (dimethylamine-co-epichlorohydrin) as an alternative to alum for the demulsification of commercial dishwasher wastewater. *Sep. Purif. Technol.* **2018**, *195*, 281–287. [CrossRef]
9. Johansson, J.; Luttropp, C. Material hygiene: Improving recycling of WEEE demonstrated on dishwashers. *J. Clean. Prod.* **2009**, *17*, 26–35. [CrossRef]
10. Abeliotis, K.; Dimitrakopoulou, N.; Vamvakari, M. Attitudes and behaviour of consumers regarding dishwashing: The case of Patras, Greece. *Resour. Conserv. Recycl.* **2012**, *62*, 31–36. [CrossRef]
11. Richter, C.P. Automatic dishwashers: Efficient machines or less-efficient consumer habits. *Int. J. Consum. Stud.* **2010**, *34*, 228–234. [CrossRef]
12. De Hoog, G.S. Beware of your dishwasher! *Pers. Mol. Phylogeny Evol. Fungi* **2010**, *25*, 117–118. [CrossRef]
13. Zupančič, J.; Babič, M.N.; Zalar, P.; Gunde-Cimerman, N. The black yeast exophiala dermatitidis and other selected opportunistic human fungal pathogens spread from dishwashers to kitchens. *PLoS ONE* **2016**, *11*, e0148166. [CrossRef]
14. Zupančič, J.; Raghupati, P.K.; Houf, K.; Burmølle, M.; Sørensen, S.J.; Gunde- Cimerman, N. Synergistic interactions in microbial biofilms facilitate the establishment of opportunistic pathogenic fungi in household dishwashers. *Front. Microbiol.* **2018**, *9*, 21. [CrossRef]
15. Zupančič, J.; Turk, M.; Črnigoj, M.; Ambrozic Avgustin, J.; Gunde-Cimerman, N. The dishwasher rubber seal acts as a reservoir for bacteria in the home environment. *BMC Microbiol.* **2019**, *19*, 1–15. [CrossRef] [PubMed]
16. Koren, S.; Kovač, M.; Toplak, N. Who lives in our dishwasher? Preliminary results of fungal metagenomics analysis of household dishwashers. *Acta Agric. Slov.* **2015**, *16*, 5–12. [CrossRef]
17. Zalar, P.; Novak, M.; de Hoog, G.S.; Gunde-Cimeran, N. Dishwashers—A man-made ecological niche accommodating human opportunistic fungal pathogens. *Fungal Biol.* **2011**, *115*, 997–1007. [CrossRef] [PubMed]
18. Raghupathi, P.K.; Zupančič, J.; Brejnord, A.D.; Jacquiod, S.; Houf, K.; Burmølle, M.; Gunder-Cimerman, N.; Sørensen, S.J. Microbial Diversity and Putative Opportunistic Pathogens in Dishwasher Biofilm Communities. *Appl. Environ. Microbiol.* **2018**, *84*, e02755-17. [CrossRef]
19. Döğen, A.; Kaplan, E.; Öksüz, Z.; Serin, M.S.; Ilkit, M.; de Hoog, G.S. Dishwashers are a major source of human opportunistic yeast-like-fungi in indoor environments in Mersin, Turkey. *Med. Mycol.* **2013**, *51*, 493–498. [CrossRef]
20. Yoshida, M.; Furuya, N.; Hosokawa, N.; Kanamori, H.; Kaku, M.; Koide, M.; Higa, F.; Fujita, J. Legionella pneumophila contamination of hospital dishwashers. *Am. J. Infect. Control.* **2018**, *46*, 943–945. [CrossRef]
21. Muhsen, W.S.; Khadim, M.F. Dishwater-related injuries: Survey and literature review. *Int. J. Inj. Control. Saf. Promot.* **2015**, *22*, 86–88. [CrossRef] [PubMed]
22. Sheridan, R.L.; Sheridan, M.G.; Tompkins, R.G. Dishwasher effluent burns in infants. *Pediatrics* **1993**, *91*, 142–144. [PubMed]
23. Jeppsson, P.H.; Ejnell, H. Mucous membrane damage inflicted by dishwasher detergent. *Lakartidningen* **1980**, *77*, 642–644. [PubMed]
24. Cornish, L.S.; Parsons, B.J.; Dobbin, M.D. Automatic dishwasher detergent poisoning: Opportunities for prevention. *Aust. N. Z. J. Public Health* **1996**, *20*, 278–283. [CrossRef]
25. Hannu, T.J.; Riihimäki, V.E.; Piirilä, P.L. Reactive airways dysfunction syndrome from acute inhalation of dishwasher detergent powder. *Can. Respir. J.* **2012**, *19*, e25–e27. [CrossRef]
26. Davis, M.G.; Casavant, M.J.; Spiller, H.A.; Chountirath, T.; Smith, G.A. Pediatric exposures to laundry and dishwasher detergent in the United States. *Pediatrics* **2016**, *137*, e20154529. [CrossRef]
27. Bertinelli, A.; Hamill, J.; Mahadevan, M.; Miles, F. Serious injuries from dishwater powder ingestions in small children. *J. Paediatr. Child Health* **2006**, *42*, 129–133. [CrossRef]
28. Kynaston, J.A.; Patrick, M.K.; Shepherd, R.W.; Raivadera, P.V.; Cleghorn, G.J. The hazards of automatic dishwasher detergent. *Med. J. Aust.* **1989**, *151*, 5–7. [CrossRef]
29. Madarikan, B.A.; Lari, J. Ingestion of dishwater detergent by children. *Br. J. Clin. Pract.* **1990**, *44*, 35–36.

30. Richter, C.P. Usage of dishwashers: Observation of consumer habits in the domestic environment. *Int. J. Consum. Stud.* **2011**, *35*, 180–186. [CrossRef]
31. Stamminger, R.; Streichardt, C. Selected aspects of consumer behaviour in the manual and mechanical dishwashing in Germany. *SOFW-J.* **2009**, *135*, 50–56.
32. Berkholz, P.; Stamminger, R.; Wnuk, G.; Owens, J.; Bernarde, S. Manual dishwashing habits: An empirical analysis of UK consumers. *Int. J. Consum. Stud.* **2010**, *34*, 235–242. [CrossRef]
33. Janna, H.; Scrimshaw, M.D.; Williams, R.J.; Churchley, J.; Sumpter, J.P. From dishwater to tap? Xenobiotic substances benzotriazole and tolytriazole in the environment. *Environ. Sci. Technol.* **2011**, *45*, 3858–3864. [CrossRef]
34. Stamminger, R.; Schmitz, A. Load profiles and flexibility in operation of washing machines and dishwashers in Europe. *Int. J. Consum. Stud.* **2017**, *41*, 178–187. [CrossRef]
35. Finn, P.; O'Connell, M.; Fitzpatrick, C. Demand side management of a domestic dishwasher: Wind energy gains, financial savings and peak-time load reduction. *Appl. Energy* **2013**, *101*, 678–685. [CrossRef]
36. Fuss, N.; Bornkessel, S.; Mattern, T.; Stamminger, R. Are resource savings in manual dishwashing possible? Consumers applying Best Practice Tips. *Int. J. Consum. Stud.* **2011**, *34*, 194–200. [CrossRef]
37. Kochan, A. The steady uptake of robots for dishwasher manufacture. *Ind. Robot. Int. J.* **2005**, *32*, 220–222. [CrossRef]
38. Rocchi, P.; Rueda-Cantuche, J.M.; Boyano, A.; Villanueva, A. Macroeconomic effects of EU energy efficiency regulations on household dishwashers, washing machines and washer dryers. *Energies* **2019**, *12*, 4312. [CrossRef]
39. Stamminger, R. Modelling dishwashers' resource consumption in domestic usage in European households and its relationship to a reference dishwasher. *Tenside Surfactants Deterg.* **2020**, *57*, 479–488. [CrossRef]
40. Tecchio, P.; Ardente, F.; Mathieux, F. Understanding lifetimes and failure modes of defective washing machines and dishwashers. *J. Clean. Prod.* **2019**, *215*, 1112–1122. [CrossRef]
41. Asteasu, C.; Astiazaran, J.C.; Besga, J.M. A dishwasher design system: An application of tailor-made CAD systems versus commercial systems. *Comput. Graph.* **1992**, *16*, 395–399. [CrossRef]
42. Austria, V.A.C.; Arboleda, E.R.; Galas, E.M. Image processing of clean and dirty dishes to design and construct a fuzzy logic dishwasher. *Int. J. Sci. Technol. Res.* **2019**, *8*, 2470–2473.
43. Efe, B. Fuzzy cognitive map based quality function deployment approach for dishwasher machine selection. *Appl. Soft Comput. J.* **2019**, *83*, 105660. [CrossRef]
44. Bengtsson, P.; Berghel, J. Concept study of a new method for drying dishware in a heat pump dishwasher. *Energy Effic.* **2017**, *10*, 1529–1538. [CrossRef]
45. McDonald, A.T.; Friskney, S.H.; Ulrich, D.J. Thermal model of the dishwasher heater in air. *IEEE Trans. Ind. Appl.* **1989**, *25*, 1176–1180. [CrossRef]
46. Bengtsson, P.; Berghel, J.; Renström, R. A household dishwasher heated by a heat pump system using an energy storage unit with water as the heat source. *Int. J. Refrig.* **2015**, *49*, 19–27. [CrossRef]
47. Bengtsson, P.; Berghel, J. Study of using a capillary tube in a heat pump dishwasher with transient heating. *Int. J. Refrig.* **2016**, *67*, 1–9. [CrossRef]
48. Santori, G.; Frazzica, A.; Freni, A.; Galieni, M.; Bonaccorsi, L.; Polonara, F.; Restuccia, G. Optimization and testing on an adsorption dishwasher. *Energy* **2013**, *50*, 170–176. [CrossRef]
49. Richter, J.; Kessler, A.; Weber, T.; Heissler, H.; Gerstenlauer, M.; Wuest, M.; Stamminger, R. Developing and testing a new qualitative near infrared spectroscopy online tracking measuring system for soil detection during automatic dishwashing. *J. Near Infrared Spectrosc.* **2021**, *29*, 179–187. [CrossRef]
50. Pérez-Mohedano, R.; Letzelter, N.; Amador, C.; VanderRoest, C.T.; Bakalis, S. Positron Emission Particle Tracking (PEPT) for the analysis of water motion in a domestic dishwasher. *Chem. Eng. J.* **2015**, *259*, 724–736. [CrossRef]
51. Pérez-Mohedano, R.; Letzelter, N.; Bakalis, S. Integrated model for the prediction of cleaning profiles inside an automatic dishwasher. *J. Food Eng.* **2017**, *196*, 101–112. [CrossRef]
52. Kulesza, K.; Biedunkiewicz, A.; Nowacka, K.; Dynowska, M.; Urbaniak, M.; Stępień, L. Dishwashers as an extreme environment of potentially pathogenic yeast species. *Pathogens* **2021**, *10*, 446. [CrossRef] [PubMed]
53. Olson, D.A.; Corsi, R.L. In-home formation and emissions of trihalomethanes: The role of residential dishwashers. *J. Expo. Anal. Environ. Epidemiol.* **2004**, *14*, 109–119. [CrossRef] [PubMed]
54. Jeong, S.W.; Lee, D.H. Drying performance of a dishwasher with internal air circulation. *Korean J. Chem. Eng.* **2014**, *31*, 1518–1521. [CrossRef]
55. Persson, T. Dishwasher and washing machine heated by a hot water circulation loop. *Appl. Therm. Eng.* **2007**, *27*, 120–128. [CrossRef]
56. Mülcoğlu, O.; Güler, M.A.; Acar, E.; Demirbağ, H. Drop test simulation and surrogate-based optimisation of a dishwasher mechanical structure and its packaging module. *Struct. Multidiscip. Optim.* **2017**, *55*, 1517–1534. [CrossRef]
57. Selimli, S.; Abajja, K.M.A. Recovery of greywater thermal energy with a wire on a tube heat exchanger attached to a dishwasher. *Water Environ. Res.* **2021**, *93*, 1333–1345. [CrossRef]
58. Persson, T.; Rönnelid, M. Increasing solar gains by using hot water to heat dishwashers and washing machines. *Appl. Therm. Eng.* **2007**, *27*, 645–657. [CrossRef]
59. Blum, H.; Okwelum, E. Estimating an economic-efficient frontier for consumer choice. *Energy Effic.* **2018**, *11*, 1325–1340. [CrossRef]

60. Selimli, S.; Karabas, T.; Taskin, Y.; Karatas, M.B. Experimental study of the performance of heat recovery by a fin and tube heat exchange tank attached to the dishwasher greywater line. *Sustain. Energy Technol. Assess.* **2019**, *36*, 100552. [CrossRef]
61. Bengtsson, P.; Eikevik, T. Reducing the global warming impact of a household heat pump dishwasher using hydrocarbon refrigerants. *Appl. Therm. Eng.* **2016**, *99*, 1295–1302. [CrossRef]
62. Hauer, A.; Fischer, F. Open adsorption system for an energy efficient dishwasher. *Chem. Ing. Tech.* **2011**, *83*, 61–66. [CrossRef]
63. De Paepe, M.; Theuns, E.; Lenaers, S.; Van Loon, J. Heat recovery system for dishwashers. *Appl. Therm. Eng.* **2003**, *23*, 743–756. [CrossRef]
64. Congestri, R.; Savio, S.; Farrotti, S.; Amati, A.; Krasojevic, K.; Perini, N.; Costa, F.; Migliore, L. Developing a microbial consortium for removing nutrients in dishwasher wastewater: Towards a bio-filter for its up-cycling. *Water Sci. Technol.* **2020**, *82*, 1142–1154. [CrossRef] [PubMed]
65. Hong, Y.; Letzelter, N.; Evans, J.S.O.; Yufit, D.S.; Steed, J.W. Phosphate-free inhibition of calcium carbonate dishwasher deposits. *Cryst. Growth Des.* **2018**, *18*, 1526–1538. [CrossRef]
66. Law, D.; Gruss, R.; Abrahams, A.S. Automated defect discovery for dishwasher appliances from online customer reviews. *Expert Syst. Appl.* **2017**, *67*, 84–94. [CrossRef]
67. Sahai, D.; Peterson, E.; Li, Y. Microbiological assessment of utensils cleaned by domestic dishwashers in Ontario small establishments. *Food Prot. Trends* **2015**, *35*, 185–195.
68. Brands, B.; Schulze Struchtrup, S.; Stamminger, R.; Bockmuehl, D.P. A method to evaluate factors influencing the microbial reduction in domestic dishwashers. *J. Appl. Microbiol.* **2020**, *128*, 1324–1338. [CrossRef]
69. Rehberg, L.; Frontzek, A.; Melhus, Å.; Bockmuehl, D.P. Prevalence of β-lactamase genes in domestic washing machines and dishwashers and the impact of laundering processes on antibiotic-resistant bacteria. *J. Appl. Microbiol.* **2017**, *123*, 1396–1406. [CrossRef]
70. Howard-Reed, C.; Corsi, R.L.; Moya, J. Mass transfer of volatile organic compounds from drinking water to indoor air: The role of residential dishwashers. *Environ. Sci. Technol.* **1999**, *33*, 2266–2272. [CrossRef]
71. Ontañón, I.; Téllez, J.; Ferreira, V.; Escudero, A. Air inside a dishwasher: Odour characterization and strategy for measuring odour changes. *Flavour Fragr. J.* **2018**, *34*, 75–89. [CrossRef]
72. O'Connor, H.; Armstrong, N. An evaluation of washer-disinfectors (WD) and dishwashers (DW) effectiveness in terms of processing dental instruments. *J. Ir. Dent. Assoc.* **2014**, *60*, 84–89. Available online: http://hdl.handle.net/10147/316361 (accessed on 24 July 2022). [PubMed]
73. Ebner, W.; Eitel, A.; Scherrer, M.; Daschner, F.D. Can household dishwashers be used to disinfect medical equipment? *J. Hosp. Infect.* **2000**, *45*, 155–159. [CrossRef]
74. Atamer, S.; Ercan Altinsoy, M. Sound quality of dishwashers: Annoyance perception. *Appl. Acoust.* **2021**, *180*, 108099. [CrossRef]
75. Castro, N.S. A new federal test procedure for dishwashers. *Appliance* **2003**, *60*, 32–35.
76. Boyano, A.; Moons, H. Analysing of the impacts of the revision of the Ecodesign and Energy Label regulations for household dishwashers using a stock model. *Energy Effic.* **2020**, *13*, 1147–1162. [CrossRef]
77. Cohen, A.; Keiser, D.A. The effectiveness of incomplete and overlapping pollution regulation: Evidence from bans on phosphate in automatic dishwasher detergent. *J. Public Econ.* **2017**, *150*, 53–74. [CrossRef]
78. Ståhl Wernersson, E.; Johansson, E.; Håkanson, H. Cross-contamination in dishwashers. *J. Hosp. Infect.* **2004**, *56*, 312–317. [CrossRef]
79. Venkatesh, G. Sustainable Development: The Four-fold Path to Governance. *Probl. Ekorozw.* **2013**, *8*, 63–66.
80. Tang, J. Dishwasher Particle Handling Optimisation. *Filtration + Separation*. 2017, pp. 34–37. Available online: jingshentang.com/FISE0117_Feature_-_Dishwasher_2.pdf (accessed on 24 July 2022).
81. Cowan, M.E.; Allan, J.; Pilkington, F. Small dishwashers for hospital ward kitchens. *J. Hosp. Infect.* **1995**, *29*, 227–231. [CrossRef]
82. Kerschgens, S.; Artelt, J.; Brychcy, K.A.; von Esmarch-Rummler, B.; Stamminger, R. Hygienic performance of commercial dishwashers with water-change system: An experimental study. *Tenside Surfactants Deterg.* **2016**, *53*, 553–560. [CrossRef]
83. Gümral, R.; Özhak-Baysan, B.; Tümgör, A.; Saracli, M.A.; Yildiran, S.T.; Ilkit, M.; de Hoog, G.S. Dishwashers provide a selective extreme environment for human-opportunistic yeast-like-fungi. *Fungal Divers.* **2016**, *76*, 1–9. [CrossRef]
84. Gillessen, C.; Berkholz, P.; Stamminger, R. Manual dishwashing process—A pre-assigned behaviour? *Int. J. Consum. Stud.* **2013**, *37*, 286–290. [CrossRef]
85. Venkatesh, G. Circular bio-economy—Paradigm for the future: Systematic review of scientific journal publications from 2015–2021. *Circ. Econ. Sustain.* **2021**, 1–49. [CrossRef]
86. Vetter, W.; Lorenz, J. Determination of benzotriazoles in dishwasher tabs from Germany and estimation of discharge into German waters. *Environ. Sci. Pollut. Res.* **2013**, *20*, 4435–4440. [CrossRef]
87. Igos, E.; Moeller, R.; Benetto, E.; Biwer, A.; Guiton, M.; Dieumegard, P. Development of USEtox characterization factors for dishwater detergents using data made available under REACH. *Chemosphere* **2014**, *100*, 160–166. [CrossRef]