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Endocrine-disrupting chemicals and obesity risk: A review of recommendations for obesity prevention policies

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Summary

Emerging evidence indicates that industrially produced endocrine-disrupting chemicals (EDCs) may be as obesogenic as poor dietary patterns and should be considered in obesity prevention policies. The authors conducted two reviews: (a) a systematic search of four electronic databases for papers published since January 2010 to identify the policy recommendations contained in scientific reviews of EDC exposure and obesity risk and (b) a narrative review of obesity policy documents published since January 2012 to identify the recommendations of national and international agencies. A search of four electronic databases found 63 scientific reviews with policy recommendations, of which 26 suggested individual responsibility to avoid exposure, 11 suggested medical interventions to counter the effects of exposure, and 42 suggested regulatory control of hazardous chemicals. Of sixty policy documents examined, six mentioned pollutants as a possible risk factor for obesity, and only one made explicit reference to strategies for reducing exposure to EDCs. The UN Sustainable Development Goals include targets to prevent ill health from hazardous chemicals (Targets 3.9 and 12.4) and to remove unsafe industrial chemicals from the environment (Targets 6.3, 11.6, 12.4, and 14.1). The authors suggest these should be explicitly linked to World Health Assembly targets to halt the rise in obesity.

KEYWORDS
endocrine disruptors, individual responsibility, obesogens, policy

1 | INTRODUCTION

An endocrine-disrupting chemical (EDC) has been defined as "… an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub) populations"[1] and of particular concern in the present review are industrially produced EDCs that are now widely distributed in human populations.[2] Concern over industrial chemicals led the United Nations to adopt Sustainable Development Goal Target 3.9 to reduce illnesses and deaths from hazardous chemicals and pollution, and, under Goal No 12 "to ensure sustainable production and consumption patterns," Target 12.4 to ensure chemicals are produced and used in ways that "minimize their adverse impacts on human health and the environment."[3] Among the adverse impacts on human health from industrial chemicals, obesity has received little attention in policy circles, yet there is increasing evidence that EDCs influence weight regulation and have obesogenic effects from quantities found in common food packaging and household products.[2]

Two classes of substances incorporated into plastic products are widely shown to migrate into food and the environment: phthalates and bisphenols. A report in 2020 by the U.S. Endocrine Society[2] noted "biomonitoring data suggest that nearly 100% of the US population is exposed to phthalates on a daily basis" (p. 64) with metabolites found in blood serum, urine, amniotic fluid, and breast milk. Phthalate metabolites have also been found in more than 95% of women and children in a series of cohorts in several European countries.[4] Similarly, bisphenol metabolites are found in over 90% of the U.S. and

Canadian cohorts[5] and in over 98% of women and children in the European cohorts.[4]

Animal studies have shown these and several other EDCs (from poor waste management and polluted water supplies, road traffic emissions and tire dust, agrochemicals and pesticides, household furnishings, and common cosmetics) may be capable of influencing the regulation of body weight though disturbances to appetite, to fat cell creation (adipogenesis), and to fat retention (lipid storage).[6] In humans, observational data from cross-sectional surveys and longitudinal cohorts show evidence of dose–response relationships. For example, in utero and early life exposure to traffic pollution was associated with more rapid weight gain and higher body mass index (BMI) in mid-childhood after controlling for multiple other factors,[7] prenatal markers for persistent organic pollutants were linked to increased weight gain in infancy in seven European cohorts,[8] while baseline urinary phthalate levels were associated with weight gain over 3 years in older women.[9]

Cross-sectional surveys have consistently shown dose–response associations in populations of children and adults, with adiposity significantly linked to urinary chlorophenol pesiticides,[10] phthalates,[11] and bisphenols.[12,13] In the study by Bhandri et al.,[12] children aged 6–18 years from the U.S. National Health and Nutrition Examination Survey (2003–2008) were divided into quartiles according to the levels of urinary bisphenol A (BPA): in the lowest quartile, the prevalence of obesity was 10.0%, while in all higher quartiles, the prevalence of obesity ranged 16.8% to 22.9%. A meta-analysis by Ribeiro et al. of 73 studies,[14] most of them cross-sectional, found "a significant association between exposure to bisphenol A and overweight (OR 1.25), obesity (OR 1.50) and increased waist circumference (OR 1.50) in adults, and [an association] between exposure to 2,5-dichlorophenol and obesity in children (OR 1.80)" (p. 1).

Lastly, a meta-analysis by Wu et al.[15] demonstrated a dose–response gradient, in which every 1.0 ng/ml increase in urinary BPA above a baseline of 1.0 ng/ml increased the odds ratio for obesity by 17% (OR = 1.171) in children and by 14.9% (OR = 1.149) in adults. This incremental threshold is highly relevant to the U.S. population where CDC surveys indicate that for both children and adults, the median urinary BPA levels are around 1.5 to 2.0 ng/ml rising to over 5.0 ng/ml in the top 10% of the population and around 10 ng/ml in the 5% showing the highest levels (p. 43–44).[16] This indicates a near-doubling of the odds for developing obesity between the 50th and 90th centile of urinary levels for this single endocrine disruptor in the US adult population.

2 | EFFECT SIZES ARE COMPARABLE WITH FAMILIAL AND DIETARY INFLUENCES

Considerable research has been undertaken to estimate the opportunities for intervention in obesity prevention through examination of the main risk factors, leading to widely accepted concerns over food energy intake, energy expenditure, and sedentary behavior. However, the evidence suggests the effects on adiposity of conventionally recognized risk factors for obesity may be of a similar order of magnitude to those of EDCs reported above. The percentage of childhood overweight or obesity prevalence attributable to maternal overweight, maternal obesity, and excessive gestational weight gain range from 10% to 22%, according to Voerman et al.'s 2019 meta-analysis.[17] For sedentary behavior, children watching TV screens have increased odds for developing obesity of 13% per hour watched each day.[18] For dietary effects on overweight, consumption of healthful components of the diet (whole grain, fruit, legumes, and fish) reduced overweight/obesity risk by between 7% and 17%, while consumption of less healthful components (refined grains, red meat, and sugar-sweetened beverages) increased risk between 5% and 14%, according to Schlesinger et al.'s 2019 meta-analysis.[19]

Looking specifically at beverages, the modelled impact of reducing sugar-sweetened beverage intake by one 200-ml serving per day undertaken in the Spanish "Seguimiento Universidad de Navarra" (SUN) project led to a 15% fall in the odds for developing obesity (OR adj = 0.85), similarly a reduced intake of beer by one daily 330-ml serving decreased the odds for developing obesity by 19% (OR adj = 0.81).[20] Interestingly, a reduction of diet soda (200-ml serving) reduced the odds for developing obesity by 9% (OR adj = 0.91). This paradoxical finding is also shown in a 2020 meta-analysis by Qin et al.,[21] where an increase in sugar-sweetened beverage consumption by 250 ml per day is associated with a 12% increased risk of obesity (RR = 1.12), while an increase in artificially sweetened beverage consumption by 250 ml per day is associated with 21% increased risk for obesity (RR = 1.21).

The findings of an association between increased risk of obesity and higher consumption of artificially sweetened beverages raise the problem of confounding behaviors shown in cross-sectional dietary surveys: for example, those already at risk of developing obesity might increase their consumption of reduced-sugar beverages. However, an alternative, or complementary, explanation may be that beverage consumption in all forms raises the risk of increasing EDC consumption from plastic containers. Martinez-Steele et al. found that children with high levels of ultra-processed food consumption show higher levels of bisphenol and phthalate metabolites in their urine, in a dose–response association.[22] Food packaging and food processing are common sources of EDCs in the environment, and it is reasonable to assume that beverage containers may be increasing obesity risk from plasticizers in bottles and can linings. From these concerns, the present authors suggest that policies to tackle obesity may need to take into account a range of potential sources of EDCs in the environment that may lead to weight gain, as illustrated in Figure 1.

If the case is made for including EDCs as potential risk factors for obesity in human populations, then policies to tackle EDCs and strategies for implementing the policies need to be developed. The purpose of the present paper is to examine the opportunities suggested by experts in the field of EDCs and obesity risk and to ask whether these have been adopted in national and international obesity policy proposals. To accomplish this, the authors undertook (a) a systematic search of the recommendations made in recent scientific review papers concerned with the links between EDCs and obesity, and (b) a rapid

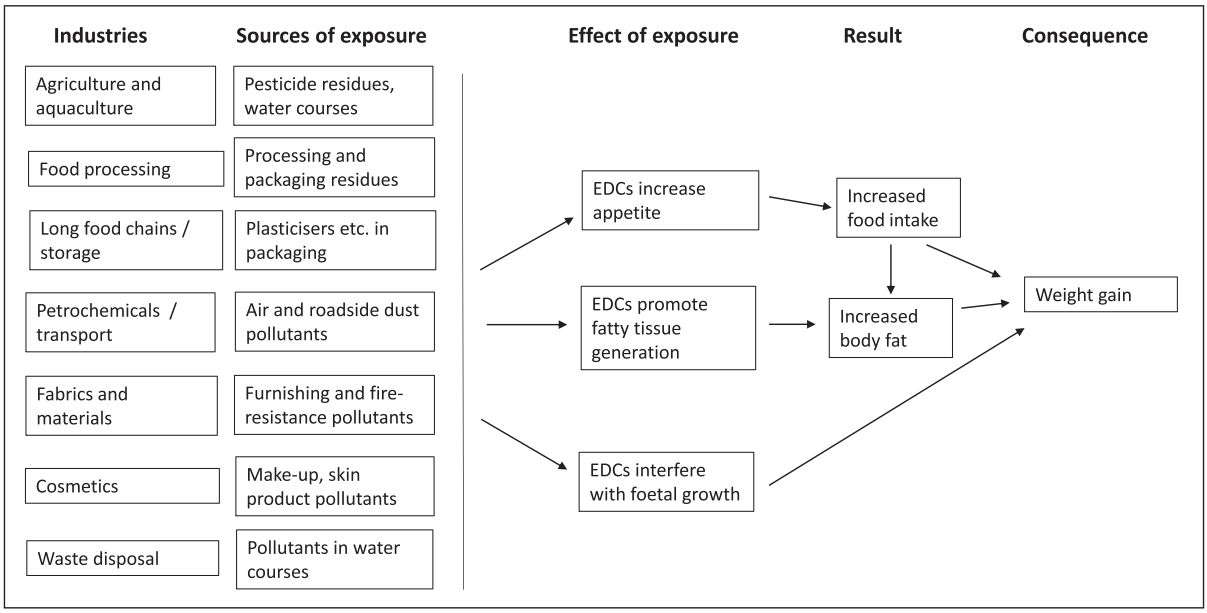

FIGURE 1 Examples of potential exposure to EDCs and consequential weight gain

TABLE 1 Inclusion criteria for retrieving review papers

	Criteria
Population	Include evidence on human populations: all age groups, genders and ethnicities. Exclude animal models, cellular models.
Intervention	Survey evidence, time series evidence, longitudinal cohorts, controlled and uncontrolled trials.
Comparator	Adiposity indicators in relation to EDC exposure; EDC indicators in relation to adiposity.
Outcomes	Recommended policies, strategies and actions to reduce adiposity or prevent excess adiposity, in relation to EDC exposure.

review of relevant national and international agencies' obesity policy documents.

3 | METHODS

3.1 | Review of policies recommended in reviews of EDCs and obesity risk

Table 1 shows the inclusion criteria in respect of the population, intervention, comparator, and outcome (PICO) details of the systematic search. Search criteria were as follows, adapted to suit the needs of each database: ("Endocrine" AND "disrupt*") AND ("obesity" OR "overweight" OR "adiposity") AND (include only reviews). Four databases were examined: (i) the US National Library of Medicine PubMed (Medline), (ii) Embase via OVID, (iii) the Cochrane Library, and (iv) Cochrane via OVID. Papers were included if they were in the English language and published after January 1, 2010, through to the time of the search, conducted in January 2021 (and updated in July 2021). Titles and abstracts were examined by one author to ensure they met the inclusion criteria. The Abstract, Discussion, and Conclusion sections of all included reviews were searched, and text was abstracted if it contained recommendations for policies and actions relevant for obesity prevention. Extracted texts were reviewed and categorized by both authors. Recommendations for further research and data collection, while important to further underpin the case for identifying EDCs as obesogens, were excluded from the present analysis that focuses on recommendations for obesity-relevant health policies.

3.2 | Review of national and international agencies' policies to reduce obesity prevalence

The authors undertook a purposive review to identify leading relevant policy documents. Using Google ® search engine (https://google.co.uk), documents were searched for using key words "obesity" or "non-communicable disease" in association with "prevention," "policy," "strategy," or "action," in combination with one of each of the following: "World Health Organization" (also with "WHO regional office"), "Australia," "Canada," "Caribbean," "European Commission," "Ireland," "New Zealand," "South Africa," "United Kingdom," and "United States." Returned listings of document titles and origins were examined for inclusion. Documents were downloaded if they were from leading intergovernmental agencies, government departments, or professional societies published in English in the period 2012–2020. Documents were examined and included if they made statements concerning population-level policies and actions relevant to healthy weight, healthy growth in childhood, or overweight and

obesity prevention. A limit of sixty documents was set, with priority given to policy statements from intergovernmental and governmental agencies. These documents were then examined for terms "endocrine," "hormone," "chemical," "disrupt+," "environmental," and "toxin," and the relevant text was extracted.

4 | RESULTS

4.1 | Review of policies recommended in reviews of EDCs and obesity risk

From the initial identification of 458 potential papers, 105 papers met the criteria for text examination of which 63 papers contained text on policy recommendations for extraction and analysis (see PRISMA chart, Figure 2). The details of the 63 review papers, and the texts extracted, are available in the Supporting Information (Table S1), along with the titles of the 42 reviews which did not meet the criteria for text extraction (Table S2). From the extracted text, the authors' recommendations were categorized under three broad headings of individual action, clinical action, and regulatory action, as shown in Table 2.

Of the 63 reviews with policy-relevant recommendations, 26 referred to individual actions to mitigate risk, including suggestions that clinicians could advice or educate patients in taking protective action. Eleven reviews suggested that therapeutic interventions could be developed to reduce or reverse the effects of EDCs. Forty-two of the reviews referred to regulatory interventions at population level to counter the obesogenic effects of EDCs, for example, through restricted production or substitution.

One of the papers examined in this review (Encarnacao et al.[26]) included a summary of "Ten recommendations to minimize exposure to EDCs" derived from individual experts and expert panels of the U.S. Endocrine Society, the World Health Organization, and the United Nations Environment Programme. These ten are given as the following:

- It is preferable to opt for fresh food instead of processed and canned foods.
- It is preferable to opt for added chemicals-free food.
- Food in plastic containers should not be heated in a microwave oven. Plastic containers can be replaced by glass or ceramic ones.
- The consumption of fat dairy or meat products should be reduced.
- Products such as makeup, perfume and skin care should be free of phthalates, parabens, triclosan and other chemicals.
- It is preferable to opt for ecological household cleaning products.
- Flame retardant treated furniture should be avoided.
- Indoors environments should be ventilated regularly.
- Alternatives to plastic toys are preferred

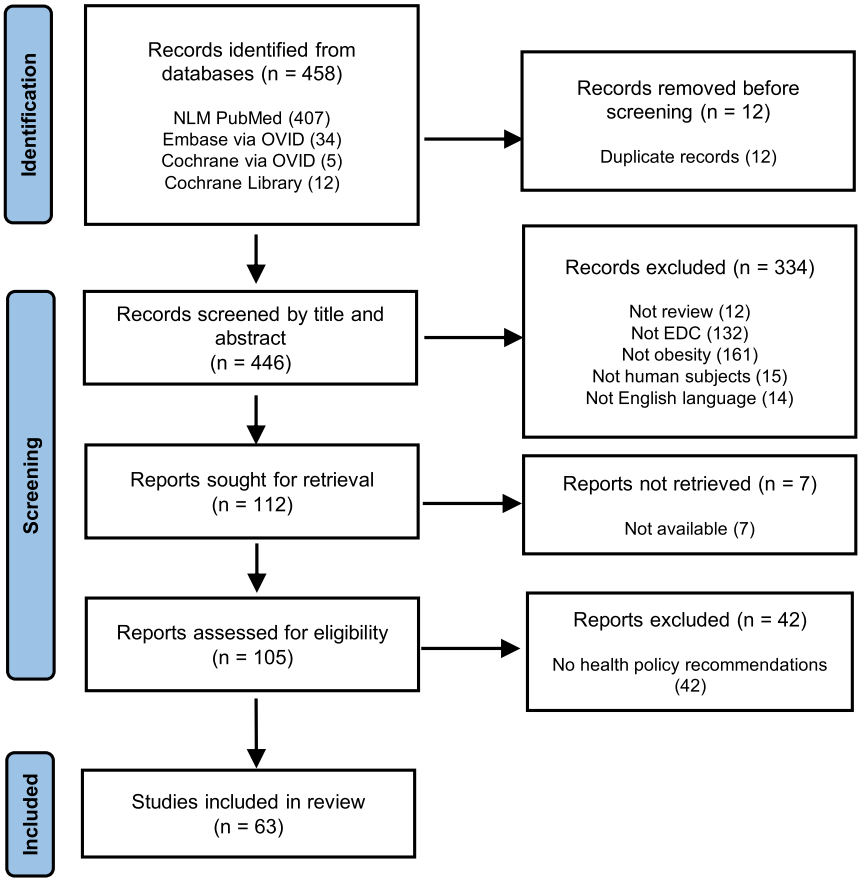

FIGURE 2 PRISMA chart for the selection of reviews of EDCs and obesity risk

TABLE 2 Types and examples of recommended policies in 63 reviews of EDCs and obesity risk

Type of recommendation	Example
Individual action: Personal choice, advice to patients, awareness raising (suggested in 26 reviews)	Eat a balanced diet, decrease or eliminate canned or packaged food consumption, reduce or eliminate the use of some lotions, cosmetics, and colognes/perfumes, and avoid triclosan-containing toothpastes.[23]
	Avoid the contact between plastic containers and food and beverage, particularly during fetal/neonatal life.[24]
	Scientific societies to communicate the risks to physicians and patients and provide materials to help people minimize exposures.[25]
	A shift in lifestyles and consumption patterns is needed. We want to live our lives in the comfort that the modern age has brought to us, but we can aim for a more sustainable and "green" future. … By changing habits of consumption, we influence commerce, industry and national and international policies.[26]
	[Individuals] can purchase consumer goods or personal care products labeled phthalate-free or BPA- free, which are becoming more commonly available.[27]
	Avoid the contact between plastic containers and food and beverage, particularly during fetal/neonatal life.[24]
	Scientific societies to communicate the risks to physicians and patients and provide materials to help people minimize exposures.[25]
	The best way to avoid BPA is to minimize plastic use. … In general, plastics marked with recycle codes 3 or 7 are more likely to contain BPA than plastics marked with other codes. Also, avoid placing plastic containers into a microwave or storing in areas of extreme heat (e.g., inside a car), as this can increase the amount of BPA that leaches into food stored in the container. The FDA also recommends that all bottles with scratches be discarded, as they may harbor bacteria and lead to greater release of BPA.[28]
	EDCs should be routinely discussed by obstetricians with their patients. One way to minimize EDC exposure is to consume organic fruits, vegetables and grain products insofar as possible …. It may also be reasonable to recommend that women minimize the use of cosmetics and personal care products containing EDC.[29]
	Pediatricians can work with families to identify ways in which children might be exposed to metabolic disruptors, and problem-solving with parents on less toxic alternatives to consumer products that contain potentially harmful properties such as plastics, pesticides, and flame retardants.[30]
	Reduce, Reuse, Recycle, Rethink, and Restrain for minimizing pre- and postnatal exposures.[31]
Medical interventions: Treatments to counter EDCs (suggested in 11 reviews)	Develop novel molecules or treatments and prevention strategies against environment-induced metabolic diseases.[32]
	Develop medical interventions to reduce EDC toxicity or eliminate EDCs from the body.[33]
	Increased understanding that the genetically based sensitivity of some people in the population to even small amounts of exposure means that they may require increased medical surveillance to anticipate and detect preclinical disease and intervene before more serious, chronic conditions [ensue].[34]
	Prediction of long-term effect of chemical exposures using genomic classifiers will facilitate assignment of treatment and development of more effective therapy.[35]
Population-level intervention: Regulation, risk assessments and chemical product licensing (suggested in 42 reviews)	Require testing strategies to adopt a precautionary approach that proactively excludes chemicals with some evidence of hazardous properties, including at low doses, and using epigenetic endpoints.[25,36]
	[E]xposure to most EDCs is multi-source, multi-pathway, and multi-route. Individual exposure scenarios depend on many factors, many of which are not modifiable through personal choices and activities. Thus, the most effective way to reduce risk is at the regulatory level.[27]
	The disputable and known pharmaceutical and environmental obesogens, such as thiazolidinediones, organotins, perfluorooctanoic acid, diisobutyl phthalate, and bisphenol A, are still used today and should be banned and removed from the environment.[37]
	[T]he definitive way to make a difference on a population level is through regulation. Regulation can eliminate environmental injustices when individuals are left to implement sometimes costly changes to their daily lives (e.g., buying organic food).[38]
	Ultimately, policy regulations are needed to reduce the production and release of EDCs into the environment. Such systems-level regulations may have wider ranging impacts than recommendations that put the onus on individuals to change behaviors and lifestyle, although in all likelihood both "top-down" and "bottom-up" activities will be needed to produce a measurable impact on obesity and other aspects of human health.[39]
	International politics must also be influenced. However, this it is not a trivial process, since each country has different declared and other interests. For example, countries which have significant heavy chemicals industry are more hostile to changes towards a greener chemicals production. Hope also lies in the cooperation between countries, such as the Basel, Rotterdam and Stockholm Conventions.[26]
	Given the fact that BPA exposure is ubiquitous, we need to conclude that BPA is a public health concern and take action to limit our exposure. European countries are reducing exposure by banning BPA in food packing materials, and a new law in France will ban the use of plastic in direct contact with food in school cafeterias.[40]

(Continues)

TABLE 2 (Continued)

Type of recommendation	Example
	This is particularly important in the current worldwide scenario of ongoing exposure of children and adults to EDCs, not only to chemicals still used for a wide range of purposes but also to compounds that were banned in many countries but have persistent and ubiquitous occurrence in the environment.[14]

Encarnacao et al. also comment in their discussion: "International politics must also be influenced. However, this it is not a trivial process, since each country has different declared and other interests. For example, countries which have significant heavy chemicals industry are more hostile to changes towards a greener chemicals production. Hope also lies in the cooperation between countries, such as the Basel, Rotterdam and Stockholm Conventions."[26] (p. 33).

4.2 | Review of national and international agencies' policies to reduce obesity prevalence

Of the 60 policy documents concerned with reducing obesity prevalence, 23 were from offices of the World Health Organization, eight from other international bodies, and the remainder from national governmental and professional agencies and organizations. The list of 60 documents is given in the Supporting Information (Table S3).

The analysis of the text in the policy documents found that only six documents contained references to the role of environmental chemicals in relation to weight gain, child growth or obesity. The relevant statements from these documents are shown in Table 3 (bold highlighting added).

Of the six documents, only one document[41] refers specifically to the role of EDCs in human health and is the only one to suggest policies to reduce exposure. The document's primary focus is on child growth rather than childhood obesity, and its recommended approaches to reducing exposure identify member state government responsibility for action and make no suggestion of personal responsibility for reducing exposure.

5 | DISCUSSION

It can be seen from Table 2 and from the expert panel suggestions summarized above that three approaches to obesity prevention and risk reduction are recommended in the scientific reviews. In 26 of the 63 reviews, individual action is proposed as a contribution to resolving the problem of EDC exposure. A narrative of individual agency or personal responsibility to defend against obesogenic chemicals unfortunately echoes the narratives of stigma and blame for weight gain in other contexts[46] and can divert attention from corporate determinants of health. While it can be argued that personal responsibility can support changes in health behavior in respect of dietary patterns,[47] several of the authors of the reviews acknowledge that there are few opportunities for personal responsibility when it comes to avoiding persistent pollutants that are pervasive in the environment.[27,38,39] Compared with sugar-sweetened beverages or snack foods, EDCs are invisible and potentially obesogenic in relatively small quantities. Expecting individuals to take responsibility for reducing exposure is unlikely to be a sufficient policy response.[48]

The second approach from the scientific reviews is to develop clinical treatments for counteracting the effects of EDCs, by reducing the toxic effects or eliminating the EDCs from the body. Susceptible individuals may be identified through genomic testing. These approaches are potentially valuable, and in the absence of population-wide reductions in exposure may be an additional strategy to complement individual action to reduce risk.

5.1 | Governmental strategies for obesity prevention

The third approach suggested in the scientific reviews is to reduce exposure to EDCs through regulatory action designed to reduce production or require substitution with safer chemical constituents or alternative products (e.g., glass containers in place of plastic) although there are warnings that untested substitutes may not prove safer and that alternative products (e.g., cardboard in place of plastic) can bring their own risks.[49]

Governmental intervention is justified when individuals cannot reasonably protect themselves from hazards created by the actions of others. While the inclusion of EDCs in obesity prevention policies may be hampered by the lack of evidence of causation, it is not ethical to deliberately expose human populations to controlled doses of EDCs to demonstrate direct effects, and the evidence base necessarily relies on animal models and population-based observational studies, as reported here and in the systematic reviews examined. This limitation can be exploited by interested parties seeking to prevent regulatory action. However, it is important to note that of the 63 reviews of EDCs and obesogenicity examined, only one, industry-funded paper recommended no action,[50] while all remaining reviews concluded there were justifications for taking action.

The evidence for EDCs as obesogens has been accumulating for nearly 20 years, and as some of the review authors note, action should be taken under the precautionary principle rather than waiting for more evidence.[25,51–53] However, as the review of obesity-related policy documents has shown, only one of the documents refers specifically to the role of EDCs in human health,[41] and it is the only one to suggest explicit strategies to reduce exposure through cleaner production and waste management, improved urban planning to reduce traffic pollution, and strengthened management of chemical development and use.

TABLE 3 EDCs or environmental toxins mentioned in 60 policy and strategy documents for obesity risk reduction

Policy document	Relevant text
Framework on Early Childhood Development in the WHO European Region (p. 16). WHO, 2020.[41]	Hazardous chemicals in the environment pose another concern. Even low-level exposure to hazardous chemicals in the environment and consumer products in early life can affect a child's development … **Exposure to endocrine-disrupting chemicals** can lead to disorders of reproductive and other hormone-regulated systems later in life, and impairment of cognitive and neurodevelopment. Countries should ensure that children have access to safe, pollutant- and chemical-free outdoor and indoor environments. … Policies and investments supporting cleaner transport, power generation and industry, energy-efficient homes and better municipal waste management would reduce key sources of outdoor air pollution. Countries should build national capacities to prevent children's exposure to hazardous chemicals through working towards sound management of chemicals, and to ensure health systems' preparedness and response to chemical-related emergencies.
Report of the WHO Commission on Ending Childhood Obesity (p. 24). WHO, 2016[42] and also noted in the report's *Implementation plan: executive summary*.	Evidence shows that maternal undernutrition (whether global or nutrient-specific), maternal overweight or obesity, excess pregnancy weight gain, maternal hyperglycemia (including gestational diabetes), smoking or **exposure to toxins** can increase the likelihood of obesity during infancy and childhood.
Action Plan for the Prevention and Control of Noncommunicable Diseases in the WHO European Region 2016–2025 (para 25). WHO, 2016..[43]	One fifth of all deaths in the European Region, particularly from cardiovascular and respiratory diseases and cancers, are attributable to environmental exposures, such as **air pollution, and chemical** and physical agents.
Adult Obesity Causes & Consequences (webpage). CDC, 2020.[44]	Research continues on the role of other factors in energy balance and weight gain such as **chemical exposures** and the role of the microbiome.
Preventing Childhood Obesity in the Caribbean – Civil Society Action Plan 2017–2021 (p. 83). HCC, 2017.[45]	*Annex of recommendations from other bodies* Develop clear guidance and support for the promotion of good nutrition, healthy diets, and physical activity, and for avoiding the use of and exposure to tobacco, alcohol, drugs, and **other toxins**. (Recommendation based on WHO Commission report, above)

5.2 | Strengthening regulatory action on EDCS

In 2013, the countries of the World Health Assembly agreed on a set of targets for preventing non-communicable diseases, including a halt to the rise in overweight and obesity.[54] In 2015, all countries of the UN General Assembly agreed to work towards achieving the Sustainable Development Goals,[3] which include several targets related to EDCs (including Target 3.9: Reduce illnesses and deaths from hazardous chemicals and pollution; Target 6.3: Improve water quality and wastewater treatment; Target 11.6: Reduce the environmental impact of cities [solid waste management]; Target 12.4: Responsible management of chemicals and waste; Target 14.1: Reduce marine pollution). From the present review, it is apparent that obesity should be considered one of the increasing number of human and planetary health issues affected by environmental chemical pollution, and measures to regulate EDCs need to be considered in obesity prevention policies.

Concern that industrial chemicals and contaminants may be responsible for a wide range of health problems other than obesity have led to a number of proposals for regulatory action. A 2020 report from the US Endocrine Society,[2] notes the impact of EDCs on raising the risk of "[c]ancers, diabetes, kidney, liver, and thyroid disorders, metabolic disorders, neurological impacts, inflammation, alterations to both male and female reproductive development, infertility, and impacts to future generations as a result of germ cell alterations" (p. 6).

The report notes "The world production of plastics in 2017 was nearly 350 million metric tons and is expected to increase to 1.1 billion tons by 2050" (p. 75) and states that more than 100 countries called for action on EDCs at the 4th International Conference on Chemicals Management in 2015. This event was one of a series of conferences undertaken to implement the Sustainable Development Goal 12 and specifically by 2020 to ensure that chemicals are produced and used in ways that minimize significant adverse impacts on human health and the environment.[3] This has not been achieved. The mechanism for coordinating this goal internationally is the UN-supported Stockholm Convention on Persistent Organic Pollutants,[55] a body that maintains a list of chemicals for immediate elimination, and others for close restriction and eventually elimination, including several associated with weight gain and obesity. While the Stockholm Convention is the main global instrument for identifying hazardous chemical substances, responsibility for enacting the necessary regulatory measures rests with national legislative bodies that are signatory to the Convention. To date (early 2021), the United States had not ratified the Convention.[36]

Other intergovernmental agencies are also involved. The World Health Organization (WHO) has developed a *WHO Chemicals Road Map* approved by the World Health Assembly of 2017.[56] The WHO's most recent assessment of the health effects of EDCs was published jointly with the United Nations Environment Programme in the report: *State of the Science of Endocrine Disrupting Chemicals – 2012*,[57] which

names many EDCs as potentially contributing to the rising levels of obesity prevalence seen in human populations (see pp. 155–156 of the report).

The WHO has a mandate to issue International Health Regulations (IHRs) that are binding on virtually all countries worldwide and can include foodborne diseases and food contamination. The WHO does not appear to have issued any IHRs relating to EDCs in food or otherwise. As with the Stockholm Convention, the *WHO Chemicals Road Map* assumes that regulatory responsibility lies with member states.

In 2019, the European Parliament called on the European Commission as the regulatory authority to "swiftly take all necessary action to ensure a high level of protection of human health and the environment against EDCs by effectively minimizing overall exposure of humans and the environment to EDCs" with a series of recommendations for greater regulatory intervention to limit production of and exposure to EDCs.[4] In 2020, the Commission responded with an assessment of its current legislative coherence and efficacy concerning EDC.[58]

A similar process was mandated by the U.S. Congress when passing the Frank A. Lautenberg Chemical Safety Act in 2016, which requires the Environment Protection Agency to review chemicals in current use, conduct fresh safety reviews, and make affirmative determinations before new chemicals can come to market[59] (see also literature[60]).

A detailed review of regulation in the United States, the European Union and in a range of other countries was published in mid-2020 by Kassotis et al.[36] The authors note specific regulatory advances, such as the banning of bisphenol A from infant feeding bottles in the European Union, and from all food containers in France, while in the United States, the Environmental Protection Agency reviewed around 2600 new chemical under the revised legislation, of which none have been prohibited. The U.S. Food and Drug Administration is responsible for chemicals in food and cosmetics and exempts chemicals that are Generally Recognized as Safe. This blanket approval of safety covers a range of EDCs including BPA, several phthalates, nonylphenol, tributyltin, and triclosan, which, as Kassotis et al. note, have for many years been legally and intentionally used in food contact materials, along with their non-intentional by-products, impurities, and breakdown compounds that also migrate into food.

Kassotis et al.'s conclusion is that a UN-supported international initiative on EDCs is needed, based on "expanded and comprehensive testing strategies to conclusively identify EDCs, and a shift from a flawed, risk-based paradigm to one that proactively excludes chemicals with some evidence of hazardous properties until further detailed reassuring testing data become available"[36] (p. 727).

The report of the Lancet Commission on the Global Syndemic of Obesity, Undernutrition and Climate Change[61] recognized that policy change requires willingness in government and pressure from civil society, and that policies which achieve multiple goals simultaneously could be especially attractive. In the present case, successful policies to reduce EDCs in line with the Sustainable Development Goals may also help to achieve the targets for preventing further increases in overweight and obesity—a potential "double duty" policy combination.[61]

5.3 | Limitations

The present study of scientific reviews was limited to examining recommendations to limit exposure to obesogens. In addition to the reviews included, it is clear there are many more reviews that consider EDCs as potential drivers of closely associated conditions including diabetes, cardiovascular disease, and metabolic disorders. Examination of these additional reviews may have led to a broader set of policy recommendations than those described here and in Table S1. Furthermore, although the present study was based on a systematic search, it included only four electronic databases and relied on one author to undertake the main selection and extraction process. The methods therefore fall between a fully systematic review and a rapid review and may suffer from bias as a consequence.

The review of policy papers for reducing obesity prevalence was undertaken in a deliberative process, based on knowledge of the likely documents available and selecting those from high-level international institutions and selected countries. A wider sweep of documents may have shown stronger evidence that EDCs are being integrated into health policy documents at national and international levels. The present paper found that this is not the case for policies aimed at obesity prevention, apart from one paper concerned more with childhood growth than with obesity. The conclusion that obesity policy documents are not recognizing EDCs as potential obesogens is supported by a 2021 review by Perng et al.,[39] which notes "Despite the relatively large body of literature on this topic, EDCs are not typically included as points of intervention in obesity prevention frameworks" (p. 23).

6 | CONCLUSION

The present review finds convincing evidence of the contribution of endocrine-disrupting chemicals to the emerging global obesity epidemic, sufficient to argue for the recognition of EDCs in national and international obesity prevalence reduction policies. The recommendations suggested in scientific reviews of EDCs and obesity risk fall into three categories: individual responsibility, clinical treatment, and regulation of the production and use of EDCs. The present review suggests that reliance on individual responsibility to avoid EDCs, along with potential medical interventions for people affected, may be valuable approaches but are likely to prove insufficient policy responses. Consequently, policy-makers are urged to pay greater attention to EDCs in the development of strategies to reduce obesity prevalence.

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AUTHOR CONTRIBUTIONS

Both authors were involved in conceiving, drafting, and editing the text.

CONFLICT OF INTEREST

No conflict of interest statement.

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