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Controversy over antibacterial silver: implications for environmental and sustainability assessments



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ABSTRACT

The potential risks and benefits of using silver, especially nanosilver, as an antibacterial agent in consumer and healthcare products are under debate globally. Using content analysis of texts from newspaper and TV, government agencies, municipalities, government and parliament, non-governmental organizations, and companies, we analyze the argumentation in the Swedish public controversy over antibacterial silver and relate the findings to environmental and sustainability assessments. We conclude that silver is regarded as either beneficial or harmful in relation to four main values: the environment, health, sewage treatment, and product effectiveness. Various arguments are used to support positive and negative evaluations of silver, revealing several contradictory reasons for considering silver beneficial or harmful. Current environmental and sustainability assessments (i.e. substance flow analysis, risk analysis, multi-criteria analysis, and lifecycle assessment) cover many of the concerns raised in the public controversy over antibacterial silver and can therefore inform the debate regarding its toxicity, emissions, and environmental impact. However, not all concerns raised in the public controversy are covered by current environmental and sustainability assessments, most notably, concerns over public health and bacterial resistance issues are not paid full attention. For future environmental and sustainability assessments to make an even more significant societal contribution and to inform consumers and decision-makers about concerns articulated in the public debate, a wider range of issues concerning antibacterial silver needs to be considered through a unified framework.

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1. Introduction

Silver is increasingly being used in consumer and healthcare products as an antibacterial agent. Data on the production and use of antibacterial silver in consumer products indicate distinct growth in its use over time. The use of antibacterial silver in Europe was estimated to total 30 tonnes per year in 2004, increasing to 110–230 tonnes per year as of 2010 (Blaser et al., 2008). Antibacterial silver sometimes occurs in the form of silver nanomaterials, or “nanosilver.” Nanomaterials are often defined as materials with at least one dimension in the size range of 1–100 nm, and there is an ongoing discussion among regulators and scientists, regarding risks and sustainability of nanotechnology (Ellenbecker and Tsai, 2011; Helland and Kastenholz, 2008). Regarding nanosilver more specifically, the question is whether it poses a higher, lower, or

similar risk compared with that of ordinary, non-nanomaterial silver (Luoma, 2008). According to the most comprehensive database on nanomaterials in consumer products, nanosilver is by far the most common nanomaterial present, used in about a quarter of all products included in the database. The number of products containing nanosilver increased tenfold from 2006 to 2012 (Project on Emerging Nanotechnologies, 2012).

The increase in antibacterial silver and nanosilver in consumer products has led to lively global debate about potential risks. For example, the global non-governmental organization (NGO) Friends of the Earth (2009, 2011) has demanded a ban on antibacterial silver until proven safe for both humans and other organisms. The controversy has led to lively public debate in Sweden over whether or not consumers should buy silver-containing products and whether regulatory action is needed in relation to different forms and applications of silver. In this controversy, a number of arguments have been made by a variety of actors to support divergent standpoints about antibacterial silver.

This article has two aims: first, to analyze the public controversy over antibacterial silver in Sweden with regard to the supportive

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and critical evaluations made and the arguments used to support these evaluations and, second, to discuss the findings of this analysis in relation to the methods and results of environmental and sustainability assessments (E&SA) of antibacterial silver. An umbrella term, E&SAs include several approaches and methods, such as lifecycle assessment, risk analysis, material and substance flow analysis, cost–benefit analysis, strategic environmental assessment, ecological footprint analysis, and multi-criteria analysis (see Finnveden and Moberg, 2005; Ness et al., 2007). In pursuing the second aim of this study, with regard to the arguments and evaluations advanced in the public controversy, we address which of these approaches and methods have been applied in assessments of antibacterial silver, as well as the results of these assessments. This overview, in turn, indicates potential venues where E&SAs can inform the public debate. However, comparing the arguments in the public controversy with these current assessments reveals challenges and limitations when it comes to informing the public debate over antibacterial silver.

Although this study focuses on the case of Sweden, similar communicative patterns to those identified here can be expected in other national contexts. Silver is internationally produced and used for antibacterial purposes. This use of silver for antibacterial purposes has been criticized internationally by, for example, the NGO Friends of the Earth (2009, 2011) as mentioned above. Both risks and benefits of antibacterial silver products have captured the attention of news media internationally.

2. Methods and materials

2.1. Analytical concepts

We understand a controversy to be a situation involving two or more actors who advance incompatible standpoints (e.g. beliefs, attitudes, and goals) regarding an issue. When questioned by an opponent, actors involved in a controversy are motivated to provide reasons for their standpoints (Toulmin, 1958/2003). We understand an argument to constitute the reasons that support or weaken a standpoint or another argument (Blair, 2012; Næss, 1961; Walton, 1990). The standpoints of the controversy examined here concern the evaluation of antibacterial silver as a “good” or “bad” thing, which in turn motivates consumer and regulatory action. Inspired by the argumentative schemes of *association* and *dissociation* suggested by Perelman and Olbrechts-Tyteca (1958/1969) and applied to risk communication by Corvellec and Boholm (2008), we suggest that a verbal argumentative controversy centered on incompatible evaluations of a certain phenomenon *x*, for example, antibacterial silver, can be analyzed in terms of a set of basic theoretical elements. These elements are: (1) *evaluations*, i.e. verbal acts of (a) *association* or (b) *dissociation* (i.e. separation) between *x* and (a) *positive value* or (b) *negative value* (see Table 1), and (2) *arguments*, i.e. verbally articulated reasons (a) supporting or (b) weakening the

Table 1
Combinations of the dichotomies of association–dissociation and negative value–positive value.

	Positive value	Negative value
Association	Silver is associated with positive value, i.e. a <i>positive evaluation</i> by association (e.g. “silver is eco-friendly”)	Silver is associated with negative value, i.e. a <i>negative evaluation</i> by association (e.g. “silver is a risk”)
Dissociation	Silver is separated from positive value, i.e. a <i>negative evaluation</i> by dissociation (e.g. “silver is not eco-friendly”)	Silver is separated from negative value, i.e. a <i>positive evaluation</i> by dissociation (e.g. “silver is not a risk”)

Table 2
Analyzed texts.

Source	Specification
Newspapers	Eighty-eight articles, from 1991 to June 2012, from twelve newspapers: first, the top ten (in terms of circulation) paid-for Swedish newspapers: the three major metropolitan morning papers <i>Dagens Nyheter</i> , <i>Svenska Dagbladet</i> , and <i>Göteborgs Posten</i> ; the local regional morning papers <i>Sydsvenska Dagbladet</i> and <i>Helsingborgs Dagblad</i> ; the evening tabloids <i>Aftonbladet</i> , <i>Expressen</i> , <i>Göteborgs-Tidningen</i> , and <i>Kvällsposten</i> ; and the daily morning financial newspaper <i>Dagens Industri</i> ; second, the two strategic additions of (i) the local regional morning paper <i>Borås tidning</i> , because Borås is the location of the Swedish School of Textiles at the University of Borås and silver is increasingly used in textiles, and (ii) the weekly newspaper <i>Ny Teknik</i> because of its focus on technology, engineering, and innovation.
TV news	TV4 (http://www.tv4play.se/): two TV news features (from December 2011 and May 2012; in total 2 min and 49 s)
Government agencies	SVT's website (http://www.svt.se/): four web pages Swedish Chemicals Agency (http://www.kemi.se/): 16 reports or web pages Medical Products Agency (http://www.lakemedelsverket.se/): three documents/reports National Food Agency (http://www.slv.se/): five reports or web pages Swedish Environmental Protection Agency (http://www.naturvardsverket.se/): four documents/reports
Swedish parliament and government	Two private members' motions, two opinion reports from parliamentary committees, and one record of the proceedings in the chamber (2 May 2011) (see http://www.riksdagen.se/) An open letter from the Minister for the Environment to the county councils (see http://www.regeringen.se/)
Municipalities	Municipality of Gothenburg (http://www.goteborg.se/): six reports or web pages Municipality of Stockholm (http://www.stockholm.se/): seven documents/reports Municipality of Malmö (http://www.malmo.se/): two documents/reports
Non-governmental organizations	Swedish Society for Nature Conservation (http://www.naturskyddsforeningen.se/): four web pages Swedish Water and Wastewater Association (http://www.svenskvatten.se/): 17 reports/documents or web pages Federation of Swedish Farmers (http://www.lrf.se/): two web pages
Companies	Polygiene (http://www.polygiene.com/): complete website (approximately 9000 words) Gryaab (http://www.gryaab.se/): two web pages Addnature (see http://www.addnature.com/ ; http://www.facebook.com/addnature ; and http://addnature.wordpress.com/): two Facebook posts including comments and a blog entry

associations or dissociations in (1). For example, the claim that “silver is toxic” is a negative evaluation that associates silver with the negative value of toxicity. The claim that “scientific studies demonstrate that silver is toxic to marine organisms” serves as an argument supporting this negative evaluation.

2.2. Textual material

In this study, we analyze texts from the following sources: news media, government agencies, parliament and government, municipalities, NGOs, and companies (see Table 2 for a detailed list of these sources). The keywords “silver” together with “bacteria” and/or “smell” (in Swedish) were used in retrieving information from the websites of government agencies, NGOs, municipalities, companies, and the Swedish parliament and government. The choice of

keywords reflects the focus of this study on silver used for anti-bacterial purposes. Our focus is not on the use of silver in general, which includes many other applications, for example in jewelry, electronics and photography development. We have no restriction with regard to any particular form of silver used for antibacterial purposes, for example nanosilver, colloidal silver or silver salt. Societal actors outside the scientific community do not always pay attention to such technical specifications of silver. Often, there is a general and vague reference to just “silver”. However, sometimes the specific form of silver is addressed, as we will see below with regard to nanosilver.

Using the same keywords, articles from the top ten (in terms of circulation) paid-for Swedish newspapers (see Nordicom, 2012), along with two strategically added newspapers, were identified through Mediearkivet Retriever, the Swedish distributor of LexisNexis (<http://www.retriever.se/tjanster/research.html>). The two strategically added newspapers are the local regional morning paper of the city of Borås, i.e. *Borås tidning*, and the national weekly newspaper *Ny Teknik*. The former was included because the city of Borås is the location of the Swedish School of Textiles at the University of Borås and silver is increasingly used in textiles. The latter was added because of its focus on technology, engineering, and innovation. To exclude hundreds of irrelevant hits in the newspaper article search, negative keywords were used, for example, “silver-tejp” (silver tape, i.e. duct tape). Concerning news coverage on Sweden’s major television channels, two news features on anti-bacterial silver aired on the privately owned TV4 were found, transcribed, and included in the analysis. Searching the archives of the Swedish public service television company (SVT) available on the Internet, no aired TV news coverage of antibacterial silver was identified, but the SVT website did present written information on antibacterial silver, which was included in the analysis. Three companies were analyzed: Polygiene is the Swedish manufacturer of a silver-based antibacterial product applied to clothes, sports gear, and hard surfaces; Gryaab is the sewage treatment utility of the Gothenburg region in southwest Sweden; and Addnature is one of Sweden’s major retailers of outdoor and adventure equipment and clothing.

2.3. Content analysis

The following research questions guide the content analysis of the texts listed in Table 2: How are antibacterial silver products evaluated? What arguments are used to support these evaluations? In an interpretative and iterative process carried out by the authors, using Atlas.ti software, categories for evaluations and arguments (“codes” in Atlas.ti) were assigned to actual segments of the analyzed texts (“quotations” in Atlas.ti). As defined above (see Table 1), the evaluation categories are: positive association (e.g. “silver is good”), positive dissociation (e.g. “silver is *not* bad”), negative association (e.g. “silver is bad”), and negative dissociation (e.g. “silver is *not* good”). In Section 2.1, an argument is defined as a reason supporting or weakening a standpoint (a primary argument) or another argument (a secondary argument). Corresponding to the four forms of evaluations, four categories of primary arguments have been used in coding: argument supporting a positive association, argument supporting a positive dissociation, argument supporting a negative association, and argument supporting a negative dissociation. In turn, four categories of secondary arguments follow, each corresponding to the four categories of primary argument, i.e. argument supporting an argument supporting a positive association, argument supporting an argument supporting a positive dissociation, etc. This coding process thus assigns categories predefined by theory (“codes”) to what is actually stated in the text (“quotations”). For example, the utterance

that “silver is a risk” has been assigned the code *negative association* and the claim “scientific studies demonstrate that silver is toxic to marine organisms,” in support of this claim, has been assigned the code *argument supporting a negative association*. The resulting set of quotations for each code was in turn analyzed to find general and systematic patterns with regard to the principal values at stake in the evaluations (e.g. environment and health) and the content of arguments; below, the types of arguments are referred to using small capital letters, for example, TOXIC ARGUMENT.

3. Analysis

3.1. Evaluations of silver

Proponents of silver associate it with a positive value (“silver is good”) or dissociate it from a negative value (“silver is *not* bad”), while opponents associate silver with a negative value (“silver is bad”) or dissociate it from a positive value (“silver is *not* good”). Associations and dissociations are, however, not always this explicitly formulated (e.g. “silver is good”), but instead implied by words that presuppose positive or critical evaluations. For example, silver is frequently characterized as a “toxin,” “danger,” “risk,” “threat,” and “problem” (or as “toxic,” “dangerous,” “risky,” “problematic,” and “harmful”). In addition, silver is characterized as something to “worry about,” “warn against,” “forbid,” “stop,” “avoid,” “criticize,” and “report,” which all imply that silver is something adverse, since the objects of worry, warnings, prohibition, etc., are adverse matters. Examples of negative dissociations include claims that silver is *not* efficient, safe, or healthy and imperatives to *not* buy, sell, and use silver.

In positive evaluations, silver is associated with outcomes such as “freshness,” “good hygiene,” “cleanness,” “good washing,” “reduction of bad smell,” “reduction of environmental impact,” and user “confidence.” Furthermore, silver products are characterized as “efficient,” “safe,” “eco-friendly,” and “climate smart.” In contrast to the negative associations, silver is claimed *not* to be toxic, dangerous, risky, problematic, or harmful.

In many of the negative associations, silver is represented as something of negative value by presupposing that it harms a positive value. Likewise, silver is represented to have a positive value through its presupposed reduction of a negative value. For example, a claim that “silver is a danger to the environment” associates silver with the negative value of being “a danger to the environment,” but this expression in turn refers to a positive value at stake, namely “the environment.” Similarly, the positive evaluation “silver reduces environmental impact” associates silver with the positive value of reducing environmental impact, which in turn contains the negative value of “environmental impact,” which embeds the positive value of the environment.

Considering explicit and implicit evaluations of silver as well as these embedded structures, there are four core values of concern in the Swedish controversy over antibacterial silver: the environment, health, the sewage treatment industry, and the quality of silver-based antibacterial products. The main proponent of silver in the Swedish debate is the company Polygiene, which evaluates silver positively in relation to all four of these values. The company Addnature also defends silver products in relation to the value of the environment. Positive evaluations of silver are also found in newspaper coverage. Critical views of silver, on the other hand, are found on the websites of government agencies, municipalities, NGOs, the company Gryaab, in government documents, and in the media material. Concerns over environmental and health issues are expressed by most of these actors, while concerns regarding silver as a sewage treatment issue are expressed primarily by the Swedish Water and Wastewater Association. The following sections present

Table 3
Summary of arguments and sources.

Argument	Source ^a
Toxicity	
TOXIC ARGUMENT	Addn, ^b EPA, Got, Gov, Gry, KEMi, LRF, MPA, Newsp (26%), NFA, Par, SSNC, Sto, SWWA, TV Addn, ^b Newsp (5%), Pol
NOT TOXIC ARGUMENT	EPA, Got, Gry, KEMi, Mal, MPA, Newsp (7%), SSNC, Sto, SWWA, TV ^c
POLLUTED SLUDGE ARGUMENT	Newsp (1%), Pol
NO POLLUTED SLUDGE ARGUMENT	KEMi, Newsp (3%), SSNC, SWWA, TV*
LOW QUANTITY SUFFICES ARGUMENT	Got, Gry, Newsp (7%), TV ^c
MERCURY ARGUMENT	Addn, Newsp (2%), Pol
SILVER SULFIDE ARGUMENT	Addn, ^b Got, Gov, KEMi, LRF, Newsp (25%), Par, SSNC, Sto, SWWA, TV
Exposure and emissions	
EMISSION ARGUMENT	Addn, Newsp (5%), Pol
NO EMISSION ARGUMENT	SSNC
HIGH QUANTITY IS USED ARGUMENT	Newsp (3%), Pol
LOW QUANTITY IS USED ARGUMENT	Got, Newsp (3%), Par
INCREASED SILVER ARGUMENT	Newsp (1%), Pol
NO INCREASED LEVEL ARGUMENT	KEMi
FOOD ARGUMENT	Gov, KEMi, Newsp (5%), TV ^c
NON-BIODEGRADABLE ARGUMENT	Got, KEMi, Newsp (2%), Sto, SWWA
BIOACCUMULATION ARGUMENT	
Reduced environmental impact	
REDUCED ENVIRONMENTAL IMPACT ARGUMENT	Newsp (1%), Pol
LESS WASHING ARGUMENT	Addn, Newsp (6%), Pol
NOT LESS WASHING ARGUMENT	Addn, ^b Newsp (2%)
LESS CONSUMPTION ARGUMENT	Pol
LESS DETERGENT ARGUMENT	Newsp (2%), Pol
LESS ENERGY ARGUMENT	Newsp (5%), Pol
LESS WATER ARGUMENT	Newsp (2%), Pol
LAST LONG ARGUMENT	Newsp (1%), Pol
LIGHT TRAVEL ARGUMENT	Pol
LOW-TEMPERATURE ARGUMENT	Newsp (5%), Pol
APPROPRIATE USE ARGUMENT	Addn, Newsp (1%), Pol
ANTIBACTERIAL ARGUMENT	The antibacterial function of silver is mentioned and acknowledged by all sources
AVOIDS TOXIC SUBSTANCE ARGUMENT	Newsp (3%)
SCARCE RESOURCE ARGUMENT	Par
RECYCLING ARGUMENT	Newsp (1%), Pol
Health and hygiene	
FIGHT INFECTION ARGUMENT	Newsp (8%), Pol
FIGHT VIRUSES ARGUMENT	Newsp (1%), Pol
NOT FIGHT VIRUSES ARGUMENT	Newsp (1%)
SAFE IN CONTACT WITH BODY ARGUMENT	Newsp (1%), Pol
CREATES SAFE ENVIRONMENT ARGUMENT	Newsp (1%), Pol
REDUCES PAIN ARGUMENT	Newsp (1%)
SCAR REDUCTION ARGUMENT	Newsp (1%)
REDUCES COSTS ARGUMENT	Newsp (1%)
REDUCES HOSPITAL STAYS ARGUMENT	Newsp (3%)
Bacterial resistance	
RESISTANCE ARGUMENT	EPA, Got, Gov, KEMi, Mal, MPA, Newsp (25%), NFA, Par, SSNC, Sto, SWWA, TV ^c
NO RESISTANCE ARGUMENT	Newsp (3%), Pol
REDUCES RISK OF RESISTANCE ARGUMENT	Newsp (2%)
HISTORICAL CO-EXISTENCE ARGUMENT	Newsp (2%), Pol
Effectiveness and marketing	
EFFECTIVE ARGUMENT	Newsp (8%), Pol
INEFFECTIVE ARGUMENT	KEMi, MPA, Newsp (22%), Par, SSNC, SWWA, TV ^c
UNIQUE ARGUMENT	Pol
INGENUOUS ALTERNATIVES ARGUMENT	Addn, ^b Gry, Newsp (3%), Par, SWWA
MISLEADING MARKETING ARGUMENT	KEMi, Newsp (14%), SSNC, SWWA, TV ^c
LABEL ARGUMENT	Newsp (1%), Pol
NO NEED ARGUMENT	Addn, ^b Gry, KEMi, Mal, Newsp (11%), NFA, SSNC, SWWA, TV
SWEAT SMELL IS OK ARGUMENT	Addn, ^b Gry, Newsp (3%)
NATURE OVER SILVER BENEFITS ARGUMENT	Addn, ^b Newsp (1%)
RISKS OUTWEIGH BENEFITS ARGUMENT	Addn, ^b KEMi, Sto
BENEFITS OUTWEIGH RISKS ARGUMENT	Newsp (1%)

Table 3 (continued)

Argument	Source ^a
Nano	
NANO ARGUMENT	KEMi, Newsp (8%), EPA, TV ^c
NOT NANO ARGUMENT	Addn, Pol
Authority and expert opinion	
ARGUMENT FROM EXPERT OPINION	Addn, Got, KEMi, Mal, MPA, Newsp (32%), Par, Pol, SSNC, Sto, SWWA, TV
ARGUMENT FROM NO EXPERT OPINION	Addn, KEMi, Newsp (3%), NFA
CERTIFICATION ARGUMENT	Addn, Newsp (1%), Pol
NO CERTIFICATION ARGUMENT	SWWA
LEGISLATION ARGUMENT	Addn, Newsp (3%), Pol, TV

Key: Addn = Addnature; EPA = Swedish Environmental Protection Agency; Got = Municipality of Gothenburg; Gov = Swedish Government (the Minister for the Environment); Gry = Gryaab; KEMi = Swedish Chemical Agency; LRF = Federation of Swedish Farmers; Mal = Municipality of Malmö; MPA = Medical Product Agency; Newsp = Newspaper media; NFA = National Food Agency; Par = The Swedish Parliament; Pol = Polygiene; SSNC = Swedish Society for Nature Conservation; Sto = Municipality of Stockholm; SWWA = Swedish Water and Wastewater Association; TV = TV news media.

^a Percentage within brackets show proportion of newspaper articles ($n = 88$) that include the argument in question.

^b The argument in question is advanced among the comments on Addnature's Face book page; it is not advanced by an Addnature representative.

^c The argument is advanced on the website of the Swedish public service television company SVT.

the arguments advanced to support these evaluations (see Table 3 for summary).

3.2. Toxicity

One of the main arguments supporting evaluations that silver is bad (or not good) for the environment, health, and the sewage treatment industry is the claim that it is toxic to organisms, i.e. the TOXIC ARGUMENT. As an environmental issue, concerns are raised about silver's toxic effects on organisms in the environment, especially marine animals (including fish and crustaceans). Concerning silver as a health issue, no explicit claims are made that silver is toxic to humans, but this is arguably suggested in the following quotations:

It cannot be good if children ingest these substances [including silver] when they suck on their clothes.

SVT, 2011.

In Japan there are, for example, packages that release zinc and silver ions into the food. That is not very healthy, says [the expert] Anders Leufvén. (*Göteborgs Posten*, 10 October 2002: "Aktiv förpackning gör maten mer hållbar" [Active package makes the food sustainable])

Concerning sewage treatment issues, two reasons are provided for why silver is problematic. First, silver is toxic to the beneficial bacteria used in cleaning wastewater. Second, the sludge produced by the sewage treatment plant becomes contaminated with silver (POLLUTED SLUDGE ARGUMENT), preventing its use as fertilizer. The use of sludge in agriculture solves both a disposal problem for sewage treatment plants and implements environmental policy calling for nutrient recycling, in particular, of the phosphorous in the sludge (see Bengtsson and Tillman, 2004).

Two arguments that support the TOXIC ARGUMENT are the LOW QUANTITY SUFFICES ARGUMENT and the MERCURY ARGUMENT. The former says that silver is toxic even in small doses, following the rationale that the less of a substance is required for toxic effects to arise, the more toxic it is. The MERCURY ARGUMENT exploits mercury's more familiar and already established association with toxicity and says that silver is

as toxic as mercury; there are even claims that silver is *more* toxic than mercury.

Proponents of silver argue that silver lacks toxic effects on humans or other organisms in the environment, including those used in sewage treatment (NOT TOXIC ARGUMENT). Polygiene claims that the sludge produced by the sewage treatment works is not adversely affected by the silver in their products (NO POLLUTED SLUDGE ARGUMENT). Furthermore, the SILVER SULFIDE ARGUMENT supports the NOT TOXIC ARGUMENT in claiming that any toxic silver ions react with sulfur compounds (sulfides) in the water, resulting in harmless silver sulfide. This argument is, however, denied by opponents who invoke the NO SILVER SULFIDE ARGUMENT; for example, the [Swedish Water and Wastewater Association \(2012\)](#) says: “Polygiene asserts that their product is transformed into silver sulfide and accordingly the environmental problems are eliminated. This is not true.”

3.3. Exposure and emissions

For silver actually to harm organisms, it must be toxic *and* come into contact with organisms, i.e. exposure must occur. The argument that silver is emitted from products into wastewater or food (EMISSION ARGUMENT) constitutes such reasoning. Suggested causes of silver emissions include children’s sucking on silver-treated clothes (see quotation in Section 3.2), washing silver-containing clothes, and using washing machines with a silver function. Furthermore, silver is claimed to be used in large doses in certain products (HIGH QUANTITY IS USED ARGUMENT), enabling high emissions of silver. Concerns about silver emissions to wastewater are reinforced by claims that these emissions into wastewater are increasing (INCREASED SILVER ARGUMENT).

Different exposure pathways are outlined in the debate depending on whether silver is considered an environmental, health, or sewage treatment issue. With regard to sewage treatment, the concern is that the silver emitted from products into wastewater during washing ends up in the wastewater treatment plant. Regarding silver as a health issue, a direct exposure route is suggested in the quotation in Section 3.2, referring to children sucking on silver-treated clothes. More elaborated exposure routes are suggested in claims that silver ends up in food (FOOD ARGUMENT). See, for example, the quotation in Section 3.2, which states that silver can be emitted from packages into food. Even more elaborated concerns over how silver ends up in food are articulated in the empirical material: silver is emitted into wastewater from washing silver-treated products (EMISSION ARGUMENT) and ends up in the sewage treatment plant where it pollutes sludge (POLLUTED SLUDGE ARGUMENT), which in turn is used in agriculture, ultimately entering our food (FOOD ARGUMENT). As an environmental issue, marine organisms are exposed when silver emissions reach water, but there is also the worry that terrestrial organisms may be affected when polluted sludge is spread on farmland. Further arguments that support potential exposure are claims that silver accumulates in organisms (BIOACCUMULATION ARGUMENT) and that silver not is biodegradable (NON-BIODEGRADABLE ARGUMENT).

Questioning the EMISSION ARGUMENT, the NO EMISSION ARGUMENT says that there are no (or negligible) silver emissions into wastewater and the environment. Polygiene characterizes its product as “permanent” and denies that any significant amounts of silver are washed out of the garments. In contrast to the HIGH QUANTITY IS USED ARGUMENT, the LOW QUANTITY IS USED ARGUMENT says that only small amounts of silver are used in products. That there is an increased level of silver in wastewater is denied (NO INCREASED LEVEL ARGUMENT).

3.4. Reduced environmental impact

In denying that silver is toxic or that organisms are exposed to it, silver’s proponents advocate evaluating silver positively by

dissociation (silver is *not* bad). Denying toxicity and exposure to silver, however, does not support the evaluation that silver is *good* for the environment. The REDUCED ENVIRONMENTAL IMPACT ARGUMENT, however, does support such an evaluation. It says that silver-based products have less environmental impact than alternative products do, so the use of silver-based products, rather than the alternatives, reduces environmental impact.

Proponents of silver emphasize that silver products need to be assessed from a lifecycle perspective. In this vein, a number of “less x” arguments are used to support the REDUCED ENVIRONMENTAL IMPACT ARGUMENT. The following reasoning demonstrates the rationale for these arguments: since silver kills bacteria (ANTIBACTERIAL ARGUMENT) that produce bad smell in garments, there will be less need to wash them (LESS WASHING ARGUMENT) and therefore less use of washing detergent (LESS DETERGENT ARGUMENT), energy (LESS ENERGY ARGUMENT), and water (LESS WATER ARGUMENT). It is also claimed that antibacterial silver makes it possible to wash clothes clean at a lower temperature (LOW-TEMPERATURE ARGUMENT), which reduces energy use even further. Since less frequent washing of a garment will make it last longer (LAST LONG ARGUMENT), clothing consumption will be reduced (LESS CONSUMPTION ARGUMENT), which also reduces environmental impact. That silver products kill (malign) bacteria (ANTIBACTERIAL ARGUMENT) is invoked to support the LAST LONG ARGUMENT more directly than by reducing washing, in that silver is said to kill bacteria that break down clothing fibers. Another form of reasoning about how silver reduces environmental impact is the LIGHT TRAVEL ARGUMENT. According to this argument, one can bring less clothing when traveling: since silver-treated clothing stays fresh longer, there is less need to change clothes because they smell sweaty. Related to the LESS DETERGENT ARGUMENT is the AVOIDS TOXIC SUBSTANCE ARGUMENT, i.e. since silver is used to kill bacteria, the alternative and allegedly more dangerous substance triclosan is avoided.

The LESS WASHING ARGUMENT is questioned by the argument that people do not in fact wash silver-treated clothing less than other clothing (NOT LESS WASHING ARGUMENT). In response, Polygiene and Addnature emphasize that their products nevertheless enable consumers to wash clothes less and that consumers need to learn this. Appropriate product handling, i.e. that people should wash their silver-treated clothes LESS (APPROPRIATE USE ARGUMENT), would indeed reduce the environmental impact, according to this reasoning.

Another form of environmental impact considered in this controversy is the use of nonrenewable resources. In the parliamentary debate analyzed (see Table 2), concern is expressed over silver as a scarce resource (SCARCE RESOURCE ARGUMENT), questioning its use in sports gear. Polygiene, on the other hand, argues that only recycled silver is used in their products (RECYCLING ARGUMENT), thereby “conserving resources.” Also note that the arguments of LESS CONSUMPTION, LESS WATER, and LAST LONG are relevant in this context, since they support the claim that the use of silver, given this reasoning, reduces the exploitation of limited resources.

3.5. Health and hygiene

In contrast with some toxic claims, silver is asserted to be good for health since it kills (malign) bacteria (ANTIBACTERIAL ARGUMENT), fights infections (FIGHT INFECTION ARGUMENT), and even viruses (FIGHT VIRUSES ARGUMENT). For example, Polygiene claims on its website that the product has been proven effective against bacteria, viruses, fungi, mold, and mildew, including especially problematic forms of bacteria and viruses such as those causing severe acute respiratory syndrome (SARS) and avian flu. Newspaper coverage contains statements that colloidal silver fights influenza, i.e. a disease caused by viruses, though such claims are also denied in the media material (NOT FIGHT VIRUSES ARGUMENT). In more general terms, silver products are considered to enable hygienic, clean, and safe places

and surroundings (CREATES SAFE SURROUNDINGS ARGUMENT). Silver is asserted to be safe in contact with the human body (SAFE IN CONTACT WITH BODY ARGUMENT), for example, the skin or the eyes.

In early media discussions, the specific application of silver in burn injury bandages is attributed a number of health benefits. Similar to the AVOIDS TOXIC SUBSTANCE ARGUMENT discussed in Section 3.4, the use of silver-treated bandages is claimed to prevent the need of using narcosis. Furthermore, it is said to reduce scar tissue formation (SCAR REDUCTION ARGUMENT) and pain (REDUCES PAIN ARGUMENT), since the use of silver-treated bandages reduces the need for the painful re-bandaging of wounds. While not directly supporting the claim that silver is good for health per se, but instead supporting the claim that silver is good for *healthcare*, the use of silver bandages is also said to reduce hospital stays and costs (REDUCES HOSPITAL STAYS ARGUMENT and REDUCES COSTS ARGUMENT).

3.6. Bacterial resistance

There are two conceptions of how silver is bad for health: first, silver is understood as toxic to humans (TOXIC ARGUMENT) (see Section 3.2) and, second, silver is understood as causing bacterial resistance (RESISTANCE ARGUMENT), which in turn can result in serious health problems. The type of bacterial resistance is often unspecified, but is sometimes specified as resistance to silver or antibiotics. In some cases, silver resistance is explained as leading to antibiotic resistance, due to so-called “cross-resistance.”

The RESISTANCE ARGUMENT is opposed by actors who favor antibacterial uses of silver. They instead claim that there is no increased risk of bacterial resistance from using silver (NO RESISTANCE ARGUMENT). Supporting the NO RESISTANCE ARGUMENT is the HISTORICAL CO-EXISTENCE ARGUMENT, which points out that silver and bacteria have long coexisted without bacteria developing resistance to silver or in turn cross-resistance to antibiotics; if silver caused bacteria resistance, we should have observed extensive bacteria resistance already, but we have not. Early discussions of silver-treated bandages even argued that silver treatment reduces the risk of bacterial resistance (REDUCES RISK OF RESISTANCE ARGUMENT), since use of silver-treated bandages in treatment is said to prevent the use of narcosis (see Section 3.5), but also the antibiotic use that would otherwise be required.

3.7. Effectiveness and marketing

A product that is bad for the environment, health, and the sewage treatment industry is arguably a bad product; conversely, a product that is good for the environment and health is a good product. In the silver controversy, however, the quality of silver-based products is questioned for more urgent or direct reasons. First, these products are said to be ineffective and not to function as claimed (INEFFECTIVE ARGUMENT). Second, they are claimed to contain unlabeled substances (MISLEADING MARKETING ARGUMENT). Third, these silver products are claimed to solve trivial problems that do not need solving (NO NEED ARGUMENT)—critics repeatedly claim that antibacterial silver in consumer products is “unnecessary.” Fourth, the problems allegedly “solved” by the use of silver-based products are claimed to be as easily solved by alternative methods not involving silver (INGENUOUS ALTERNATIVES ARGUMENT), such as regular washing or washing at high temperature.

The INEFFECTIVE ARGUMENT is in turn supported by the EMISSION ARGUMENT, since silver is considered to be washed out of clothes. Note that this is a different use of the EMISSION ARGUMENT from that discussed in Section 3.3. Here, the rationale is that, since silver is gradually washed out of products, the products eventually lose their active substance and hence function. A further criticism of silver products is based on the ordering and hierarchy of values. By belittling the problem of bad smell from sweat, describing it as

“natural” or “ok,” the SWEAT SMELL IS OK ARGUMENT supports the NO NEED ARGUMENT; for example, “We at Gryaab think that it is completely okay to smell sweaty when you exercise” (Gryaab, 2012). Furthermore, the value of nature is claimed to outweigh the benefits of silver products in the NATURE OVER SILVER BENEFITS ARGUMENT; for example, in a comment on Addnature’s Facebook page (2012) we can read that “better nasty-smelling clothes than silver nitrate in nature.” The risks posed by silver are claimed to outweigh its benefits in the RISKS OUTWEIGH BENEFITS ARGUMENT.

A more positive picture of silver-based products is presented by its proponents. Silver-based products are said to be “effective” (EFFECTIVE ARGUMENT) and “unique” (UNIQUE ARGUMENT), which contrasts with the INEFFECTIVE ARGUMENT and the INGENUOUS ALTERNATIVES ARGUMENT. Related to the MISLEADING MARKETING ARGUMENT, the product is alleged to be appropriately labeled as containing silver (LABEL ARGUMENT). In contrast to the RISKS OUTWEIGH BENEFITS ARGUMENT, it is claimed that the benefits outweigh the risks (BENEFITS OUTWEIGH RISKS ARGUMENT).

3.8. Ambiguous associations with “nano”

Since 2002, silver has been associated with the word “nano” in newspaper coverage. Nanosilver is represented both positively and negatively. Positive representations focus on the innovation of using nanosilver in, for example, clothes, shoes, food packages, and medical equipment. Negative representations include claims that “nanosilver particles can result in problems,” that they pose an “environmental hazard,” and the like. A recent article even declares that “of all that is silver, nanoparticles are the worst” (*Ny Teknik*, 16 May 2012: “Försiktighet lönar sig” [Caution pays off]). Concerns over nanosilver have been expressed not only in media reporting, but also by the Swedish Chemicals Agency and the Swedish Society for Nature Conservation. The NANO ARGUMENT warns that silver-containing consumer and healthcare products may contain the especially toxic nanosilver. Polygiene and Addnature explain, however, that their products do not contain any nanoparticles (NOT NANO ARGUMENT). Polygiene (2012) even expresses its approval of banning nanosilver.

3.9. Authority and expert opinion

The ARGUMENT FROM EXPERT OPINION (see Walton, 1997) functions by invoking the authority of experts to support an evaluation or another argument. This argument is frequently used by both sides of the controversy. Sometimes this argument is even used to support opposing arguments regarding the same issue. For example, the ARGUMENT FROM EXPERT OPINION is invoked to support both the opponents’ RESISTANCE ARGUMENT and the proponents’ NO RESISTANCE ARGUMENT, as in the quotations below:

The risk is, according to researchers, that bacteria may become resistant to silver and in the long run develop resistance to antibiotics. (*Expressen*, 20 May 2012: “Svettiga fakta” [Sweaty facts])

In Denmark they have tested resistance to silver in all strains of antibiotic-resistant bacteria and not found any bacteria with so-called cross-resistance to antibiotics.

Polygiene, 2012.

Other pairs of opposing arguments supported by the ARGUMENT FROM EXPERT OPINION are the TOXIC–NOT TOXIC ARGUMENT, the EMISSION–NO EMISSION ARGUMENT, the POLLUTED SLUDGE–NO POLLUTED SLUDGE ARGUMENT, and the EFFECTIVE–INEFFECTIVE ARGUMENT. Furthermore, ARGUMENT FROM EXPERT OPINION is used by opponents to support the BIOACCUMULATION, NON-

BIODEGRADABLE, LOW QUANTITY SUFFICES, and INCREASED SILVER arguments, and by proponents to support the ANTIBACTERIAL, FIGHT INFECTION, FIGHT VIRUSES, SAFE IN CONTACT WITH BODY, and REDUCED ENVIRONMENTAL IMPACT arguments. Related to the ARGUMENT FROM EXPERT OPINION is the ARGUMENT FROM NO EXPERT OPINION also used by both sides of the debate, stating that expert authority in support of a claim is lacking, for example: “Samsung is of the opinion that there have not been any scientific studies that support bacterial resistance to silver” (*Dagens Nyheter*, 27 November 2006: “Varningar för silver som bakteriedödare” [Warning of silver as a bacteria killer]).

Another authority-based argument is the LEGISLATION ARGUMENT, that silver-based products meet relevant legislation and regulatory requirements. A third type of authority-based argument is the CERTIFICATION ARGUMENT, that silver-based products are certified and approved according to some standard. For example, Polygiene says that its product “meets the most demanding environmental certification for textiles,” and furthermore that it has been “approved by” Bluesign, the US Environmental Protection Agency, and the Eco Circle system (a Japanese textile-recycling program) and is registered under the EU Biocidal Product Directive and on the Oeko-Tex list of approved products. Furthermore, in relation to health concerns, the product is claimed to be “Medical Class 1 approved in Europe.” That Polygiene is Bluesign certified is, however, denied by the *Swedish Water and Wastewater Association* (2012) constituting the NO CERTIFICATION ARGUMENT: “Polygiene also pretends that its rinsing fluid product ‘Active Odeur [sic] Control’ is labeled with a so-called Bluesign label. This is completely wrong.”

4. Discussion

4.1. Environmental and sustainability assessments of antibacterial silver

Many of the arguments of the controversy analyzed above concern typical environmental and sustainability issues, such as toxic substances, emissions, resource scarcity, energy use, water use, and human health. Given the wide range of conflicting arguments for and against antibacterial silver use, and the justification of claims by invoking expert authority, we raise the following questions: What E&SA approaches and methods, relevant to this public controversy, have been applied to antibacterial silver, and what are the results of these assessments? As a first step towards answering the first question, a Scopus query (see <http://www.scopus.com/home.url>) has been made using the search string “(antibacterial OR antimicrobial OR biocidal) AND (silver OR nanosilver) AND assessment” in article titles, abstracts and keywords. From the set of 246 articles that was identified by this Scopus query, only those applying an E&SA approach (Finnveden and Moberg, 2005; Ness et al., 2007) were selected for further analysis. In addition, however, the in-press risk assessment study of antibacterial silver in clothes by Arvidsson et al. (inpress) was included as it is known to the authors and due to its relevance for the purpose of this study.

This procedure identified six studies relevant to this public controversy over antibacterial silver (Arvidsson et al., 2011, inpress; Blaser et al., 2008; Meyer et al., 2011; Walser et al., 2011; Windler et al., 2013). Four E&SA approaches (Finnveden and Moberg, 2005; Ness et al., 2007) has been applied in these studies: *substance flow analysis* (SFA), *risk analysis* (RA), *multi-criteria analysis* (MCA), and *lifecycle assessment* (LCA) (see Table 4). In SFA the magnitudes of the societal stocks, flows, and emissions of a specific substance are typically assessed. An SFA study can be regional or global, or related to a specific product group, and is mainly used to assess resource use and emissions of toxic substances (van der Voet, 2002). In RA the risk of a specific substance to specific

organisms is quantified based on toxicity and exposure data. This method can tell whether a specific substance constitutes a risk to humans or to organisms in the environment, yet it is limited to environmental and health impacts of the substance itself (van Leeuwen and Vermeire, 2007). Furthermore, RA is unable to assess positive impacts from a substance. In MCA different alternatives are evaluated and ranked based on preselected criteria. Although this method is inclusive when it comes to which negative and positive impacts that can be included, MCA has been criticized for being subjective (Dobes and Bennett, 2010). In LCA various environmental impacts are quantified for a specific product or service. LCA is inclusive when it comes to environmental impacts (and benefits), but some environmental impacts are problematic to assess in LCA (Finnveden et al., 2009). In addition, impacts and benefits over and above those related to the environment or human health are typically not included in LCA, although pioneering work is being done to extend the method into other sustainability aspects (UNEP/SETAC Life Cycle Initiative, 2011).

Some of the studies identified cover many arguments, whereas others cover only a few (see Table 4). Furthermore, an argument can be explicitly addressed by one type of method, but only indirectly assessed in another. For example, assessment of emissions, and hence the EMISSION ARGUMENT, is a main interest in SFA, but is only a

Table 4

Environmental and sustainability assessments of antibacterial silver (in alphabetical order) paired with arguments in the Swedish public controversy and the method used (see Finnveden and Moberg, 2005; Ness et al., 2007).

Study	Method	Arguments assessed as main outputs of the assessment	Arguments assessed as minor outputs of the assessment
Arvidsson et al. (2011)	Substance flow analysis	(NO) EMISSION ARGUMENT	HIGH/LOW QUANTITY IS USED ARGUMENT
Arvidsson et al. (inpress)	Risk analysis	(NO) POLLUTED SLUDGE ARGUMENT (NOT) TOXIC ARGUMENT (NO) EMISSION ARGUMENT	LOW QUANTITY SUFFICE ARGUMENT HIGH/LOW QUANTITY IS USED ARGUMENT (NO) SILVER SULFIDE ARGUMENT NON-BIODEGRADABLE ARGUMENT
Blaser et al. (2008)	Risk analysis	(NOT) TOXIC ARGUMENT (NO) EMISSION ARGUMENT (NO) POLLUTED SLUDGE (NO) INCREASED LEVEL ARGUMENT	LOW QUANTITY SUFFICE ARGUMENT HIGH/LOW QUANTITY IS USED ARGUMENT (NO) SILVER SULFIDE ARGUMENT NON-BIODEGRADABLE ARGUMENT
Meyer et al. (2011)	Lifecycle assessment	(NOT) TOXIC ARGUMENT AVOIDS TOXIC SUBSTANCE ARGUMENT (NO) EMISSION ARGUMENT REDUCED ENVIRONMENTAL IMPACT ARGUMENT	LOW QUANTITY SUFFICE ARGUMENT HIGH/LOW QUANTITY IS USED ARGUMENT LESS DETERGENT ARGUMENT LESS ENERGY ARGUMENT (NO) LESS WASHING ARGUMENT NON-BIODEGRADABLE ARGUMENT
Walser et al. (2011)	Lifecycle assessment	(NOT) TOXIC ARGUMENT AVOIDS TOXIC SUBSTANCE ARGUMENT (NO) EMISSION ARGUMENT REDUCED ENVIRONMENTAL IMPACT ARGUMENT LOW TEMPERATURE ARGUMENT	LOW QUANTITY SUFFICE ARGUMENT HIGH/LOW QUANTITY IS USED ARGUMENT LESS DETERGENT ARGUMENT LESS ENERGY ARGUMENT (NO) LESS WASHING ARGUMENT APPROPRIATE USE ARGUMENT NON-BIODEGRADABLE ARGUMENT ANTIBACTERIAL ARGUMENT
Windler et al. (2013)	Multi-criteria analysis	HIGH/LOW QUANTITY IS USED ARGUMENT BIOACCUMULATION ARGUMENT NON-BIODEGRADABLE ARGUMENT SAFE IN CONTACT WITH BODY ARGUMENT (IN)EFFECTIVE ARGUMENT INGENUOUS ALTERNATIVES/ UNIQUE ARGUMENT	

constituent of the main assessment conducted in other methods (e.g. RA or LCA).

In short, the main results of the identified E&SA studies of antibacterial silver are as follows:

- high emissions of nanosilver can occur given high use and concentration of antibacterial silver in textiles (Arvidsson et al., 2011);
- given high concentration of silver in clothes, there is high risk of polluted sludge and toxic effects on soil organisms (Arvidsson et al., *in press*);
- risks from antibacterial silver to freshwater ecosystems, in particular sediments, cannot be ruled out (Blaser et al., 2008);
- clothing containing antibacterial silver has slightly higher environmental impacts than does ordinary clothing, including slightly higher ecotoxicity impacts (Meyer et al., 2011);
- toxic substances other than silver have a much higher impact than does silver from a lifecycle perspective (Walser et al., 2011); and
- when technical, environmental, and health criteria are compared semi-quantitatively, nanosilver as an antibacterial agent in textiles performs better than do other antibacterial agents, whereas silver in salt or metallic form has among the worst performance (Windler et al., 2013).

These E&SA studies cover many of the arguments advanced in the public controversy analyzed above (see Table 4), but they do not cover all the concerns articulated (cf. Table 3). Given this gap between E&SAs and public concern, there is a lack of complete answer to what actions that are appropriate with regard to antibacterial silver (e.g. buy, sell, and regulate it, or not).

4.2. Challenges ahead

In addressing many of the arguments of the public controversy over antibacterial silver, the E&SA studies listed in Table 4 provide valuable insights that could inform the public and government actors engaged in the controversy (in Sweden as well as globally). These studies are, however, quite limited with respect to the full range of concerns raised. Far from all of the numerous arguments advanced in the controversy are covered by current E&SAs. For sure, some of the arguments advanced in the controversy are hardly the type of issues that are enlightened by science at all, i.e. the SWEAT IS OK and NATURE OVER SILVER BENEFITS arguments. Whether sweat is ok and whether nature is more important than the benefits of silver (e.g. reducing smell) are arguably genuine matters of opinion that could be subject to ethical analysis, but not through using E&SAs, at least not in any traditional sense.

Other major groups of arguments advanced in the controversy, but not currently covered by E&SAs, concern (i) resource scarcity (e.g. the RECYCLING and SCARCE RESOURCE arguments; see Section 3.4), (ii) human health (e.g. the (NOT) FIGHT INFECTION, CREATES SAFE SURROUNDINGS, and REDUCES PAIN arguments; see Section 3.5), and (iii) resistance (e.g. the (NO) RESISTANCE and REDUCES RISK OF RESISTANCE arguments; see Section 3.6). Concerning the first of these, resource scarcity-related arguments are typical concerns in E&SAs and most of these arguments could arguably be taken into account by the four E&SA methods identified and discussed in Section 4.1. The RECYCLING and SCARCE RESOURCE arguments could be included in a more detailed SFA. The LESS CONSUMPTION, LESS WATER, and LAST LONG arguments could be accounted for in a more extensive LCA. Concerning human health, LCA and RA studies can include impacts on human health (Baumann and Tillman, 2004; van Leeuwen and Vermeire, 2007), but the MCA by Windler et al. (2013) is the only E&SA covering such arguments. Concerning resistance, few E&SA methods typically cover such aspects.

Although E&SA studies of antibacterial silver cover only a few of the health and resistance aspects addressed in the public controversy, such issues have not been ignored. On the contrary, there are several studies of silver-related health issues, including assessments of resistance and of the application of silver for healthcare purposes (for reviews, see e.g. Atiyeh et al., 2007; Silver, 2003); in fact, public and government discussions of these issues likely originate from these research findings (cf. Friends of the Earth, 2011). In being so closely related to many of the arguments discussed in Sections 3.5 and 3.6, this body of research is indeed highly relevant to informing the debate and evaluating many of the health-related arguments. However, as is clear from the above overview of the debate, many concerns have been raised and many arguments advanced, so evaluating individual arguments can only partly contribute to a more general assessment of antibacterial silver. Specific findings need to be integrated into more holistic assessment methods to obtain more comprehensive results for consumers and decision-makers (i.e. recommending whether silver-containing products should or should not be bought, banned, or restricted); such a holistic aim is typical of E&SAs (Ness et al., 2007).

Although E&SAs typically aim to obtain holistic results for decision-makers, none so far handles the whole range of issues raised in the public controversy over antibacterial silver. Even attempting to do so is far from trivial and introduces the problem of how to assess the overall impacts of something. This is not primarily a problem of lacking specific data, but instead a methodological–analytical question of how to assess and compare risks and/or benefits of different kinds.

MCA aims to produce aggregated yes/no type results, based on multiple, preferably independent criteria. Such an approach thereby offers the possibility of assessing whether antibacterial silver as a whole is “good” or “bad.” It should be mentioned, however, that even though such results are considered comprehensive by many actors, MCA has also been criticized for being subjective (Dobes and Bennett, 2010). As in MCA, the various environmental impacts included in an LCA study are sometimes aggregated into a single number, which is called “weighting” (Baumann and Tillman, 2004). Such weightings are based on values and preferences, or more precisely on, for example, (i) the estimated costs of the environmental damage and the value of the resources used, (ii) international and national targets for the environmental problems in question, and (iii) the opinions of experts or leading politicians. However, such weighting methods are contested and some consider them too subjective to be used (Johnsen and Løkke, 2013); notably, the two identified LCA studies of antibacterial silver (see Table 4) did not conduct weighting.

The criticism of these approaches indicates the difficulty of assessing the overall risk of something. Still, such overall assessment is arguably important to enable E&SAs to better address the full range of concerns expressed by public and government actors, as in the case of antibacterial silver. In light of this criticism, it seems that work remains to be done to develop E&SAs into better supports for consumers and decision-makers. The controversy over antibacterial silver is not the only case in which a product is arguably beneficial in some senses but hazardous in others. The debate over, for example, nuclear power is in many ways similar in structure (Pampel, 2011). Proponents argue that nuclear power produces low greenhouse gas emissions, while opponents cite the radioactive waste and the risk of fatal accidents. Arguments related to resources, toxic substances, and human health are advanced in that controversy as well. We see a great potential for E&SAs to inform such societal controversies, both now and in the future. It is hoped that future E&SAs can be developed to better handle the potentially wide variety of issues actualized in public controversy, in a convincing and unified way.

5. Conclusion

The Swedish controversy over antibacterial silver in consumer and healthcare products involves several contradictory positions. According to its opponents, antibacterial silver is harmful to the environment, health, and sewage treatment, and is claimed to yield poor products. According to its proponents, antibacterial silver is beneficial, or at least not harmful, in relation to *exactly the same* four values. Furthermore, both sides often construct arguments by explicitly denying the arguments of their opponents, and both sides invoke scientific authority to support their arguments—even two diametrically opposed arguments can both be justified by invoking scientific authority. This situation is potentially quite confusing for consumers and decision-makers.

Given the wide variety, complexity, and nature of the concerns raised in this public controversy, we turn to E&SAs for guidance. Many of the identified arguments are covered by four different types of E&SA, i.e. substance flow analysis, life cycle assessment, multi-criteria analysis, and risk analysis. We therefore conclude that E&SAs can play an important role in informing the controversy at hand. However, we also note that some arguments, most notably related to public health and bacterial resistance, are not covered. The reasons for this divergence can be many, for example: the interests of public actors such as the media and E&SA scientists differ; similarly, different actors work and communicate within different contexts of institutional requirements, possibilities and restrictions; and by tradition, E&SAs focus on some aspects (e.g. toxicity and emissions) rather than others (e.g. bacteria resistance). Furthermore, besides the point that not all arguments are covered, it is far from clear how the wide variety of arguments can be handled in a single framework. These current limitations suggest a direction for the further development of E&SAs, to improve their ability to inform the public controversy over antibacterial silver, as well as societal controversy in general. In order to make an even more significant societal contribution, future E&SAs of antibacterial silver should address, incorporate and seek guidance from the wide variety of actual concerns articulated in society. By so doing, results of E&SAs will arguably be more relevant for stakeholders. In turn, this will require that theory and methods of E&SAs are developed in innovative ways, in order to cover, in a comprehensive manner, the wider set of issues actualized in public debate. Despite any such efforts, there will, in the end, probably be a need to acknowledge the limitations of E&SAs to fully inform every concern raised in public controversy (Tukker, 2000).

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