

Risk Analysis, Life Cycle Assessment—The Common Challenge of Dealing with the Precautionary Frame (Based on the Toxicity Controversy in Sweden and the Netherlands)

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Life cycle impact assessment (LCIA) and comparative risk assessment (RA) use the same building blocks for analyzing fate and potential effects of toxic substances. It is tacitly assumed that emission-effect calculations can give uniform and decisive answers in debates on toxicity problems. For several decades, mainstream policy sciences have taken a different starting point when analyzing decision making on complex, controversial societal issues. Such controversies in essence are thought to be caused by the fact that different actor coalitions adhere to a different, but in scientific terms equally reasonable, conceptualization or “framing” of the problem. A historical, argumentative analysis of the Dutch chlorine debate and the Swedish PVC debate shows that this is also true in the discussions on toxic substances. Three frames have been identified, which were coined the “risk assessment frame,” “the strict control frame,” and the “precautionary frame.” These frames tacitly disagree about the extent of knowledge/ignorance about the impacts of substances, the robustness/fallibility of emission-reduction schemes, and the robustness/vulnerability of nature. The latter frame, adhered to by environmentalists, seeks to judge substances mainly on their inherent safety. Under the current institutional arrangements and practices, RA and LCIA are executed mainly in line with the philosophy expressed by the risk assessment frame. This article gives various suggestions for dealing with framing in debates on toxic substances. One of the options is elaborated in somewhat more detail, i.e., the development of multiple indicators and calculation schemes for RA and LCIA that reflect the different frames. An outline is given for a possible indicator system reflecting the precautionary principle.

KEY WORDS: Policy science; decision making; life cycle assessment; risk assessment; frames; precaution; chlorine

1. INTRODUCTION

Toxicological risk analysis (RA) and life cycle assessment (LCA) are two environmental evaluation tools with different application areas, but with some building blocks in common.

LCA typically takes a product function as a starting point and defines a system, in principle consisting

of all processes that contribute to that central function (see Fig. 1). This is called the *goal and scope* step. For all processes in this system, in principle, all emissions are inventoried and summed up to time- and location-independent total emissions per substance for this system. This is called the *inventory* step.¹ The result is an inventory table that reflects for several dozen

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¹In principle, not only emissions but also extractions from the earth and other so-called interventions can be taken into account. The discussion on LCA was simplified here, and a vocabulary used that is also common in the risk analysis community. The

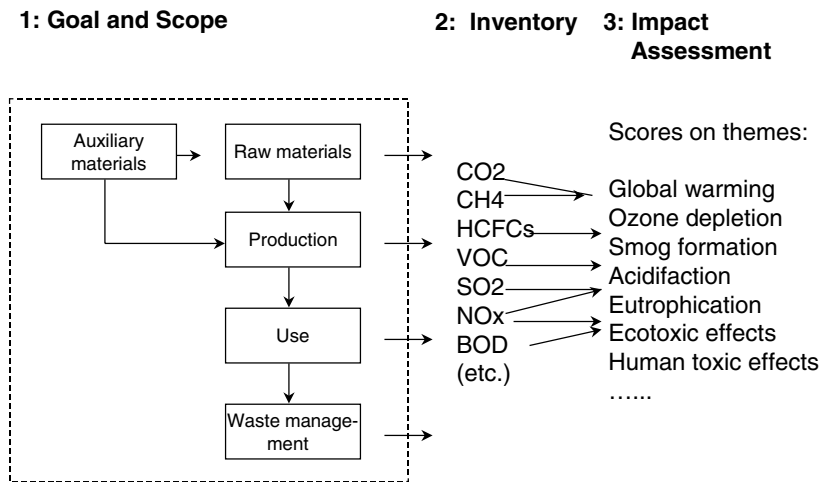


Fig. 1. The structure of LCA.

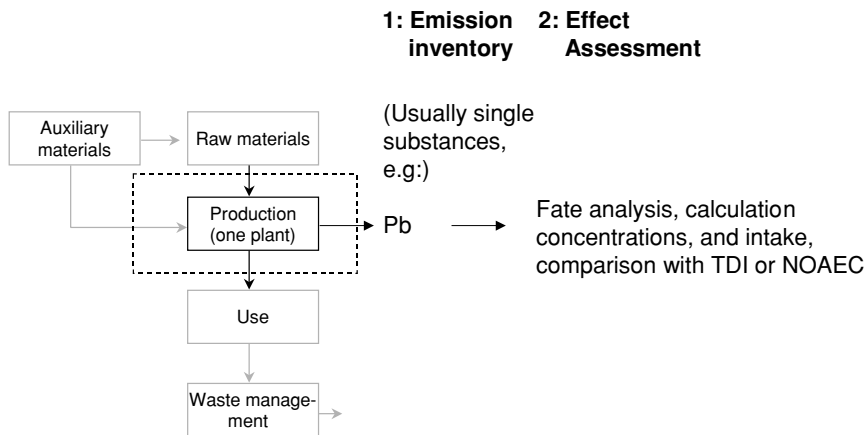


Fig. 2. The structure of RA.

substances the amount emitted if one functional unit is produced.

In contrast, RA in general concentrates on individual substances, emitted from single processes from well-defined locations. Emissions are usually (e.g., annual) totals for the plant, and not expressed per unit or product manufactured (see Fig. 2). Only in comparative RAs does a basis for the comparison of processes have to be chosen, and applying the “functional unit” concept of LCA could be a clear option.

Both in LCA and RA the impacts of these emissions somehow have to be evaluated. RA usually focuses on toxicological risks. LCA covers, in principle, all emissions from the system analyzed and includes other effect types such as acidification, eutrophication, global warming, etc. Furthermore, since in LCA the (aggregated) emission data obtained are time- and

location-independent, and related to a functional unit, only a relative/comparative assessment of potential effects is possible (e.g., between different product systems or between different parts of one product system). In RA, it is in principle possible to calculate actual risks.² However, Equations (1) and (2) show that, particularly for toxic releases, the assessment of impacts in LCA and RA can be divided into building blocks of striking similarity:³

$$S_{LCIA} = \sum_{i..j} e_i * f_i * I_i \quad (\text{for LCIA}) \quad (1)$$

2 A more comprehensive discussion about the similarities and differences between RA and LCA can be found in work of, among others, Heijungs⁽¹⁾ and Tukker.⁽¹⁶⁾

3 For the mathematical discussion behind this statement reference is made to Heijungs.⁽¹⁾ In brief, he shows that fate calculations can be elaborated in the form of a linear system of equations, implying that (small) changes in emissions lead to proportional changes in intake. Under these conditions, for a specific substance, the result of the fate calculation can be written as $e * f$. Equations (1) and (2) are examples for human toxicity; ecotoxic effects calculations are similar.

interested reader is referred to LCA manuals of, e.g., Guinee *et al.*⁽³⁴⁾ or Hauschild *et al.*⁽³⁵⁾

where:

e_i = emission (in kg/functional unit)

f_i = fate factor ($e_i * f_i$ gives a theoretical time-integrated intake in kg per kg b.w. per functional unit, related to emission pulse e_i)

I_i = impact factor (usually 1/TDI)

S_{LCA} = LCA score for human toxicity. The score is a total for all substances $i \dots j$ emitted from the system related to the functional unit.

$$S_{RA} = e_i * f_i * I_i \quad (\text{for RA}) \quad (2)$$

where:

e_i = emission (in kg/unit time)

f_i = fate factor ($e_i * f_i$ gives the daily intake in kg/kg b.w. per day)

I_i = impact factor (usually 1/TDI)

S_{RA} = RA score; if > 1 then a human toxicological risk is at stake.

Equation (1) reflects the so-called *impact assessment* step in LCA (also called Life Cycle Impact Assessment or LCIA). It typically involves a (generic) fate assessment, usually on the basis of multimedia models, combined with an effect assessment where environmental concentrations, viz. daily intakes, are expressed as a fraction of the TDI (human toxicity) or NOAEC (ecotoxicity). These scores for each substance are then aggregated to a total score on, for example, “human toxicity” for the product system analyzed. Apart from the latter aggregation step, a comparison with Equation (2) shows that the similarities with the fate models and standards used in RA are obvious. Indeed, the most advanced models of LCIA for toxic releases are thoughtful adaptations of existing RA tools, such as EUSES or CALTOX.⁽²⁾

Impact assessment in LCA and RA thus have in common a highly analytical and mathematical approach for evaluating the severity of toxic emissions, and do so solely on the basis of effect endpoints. For quite some time already within the RA community, there has been discussion of whether such analycentric tools can solve, on their own, multistakeholder discussions about risks.⁽³⁹⁾ The LCA community is beginning to face the same discussion. In a first debate, defenders of current LCA practices suggested that it is possible to make a sharp distinction between facts, uncertainties, and value choices.^(2–4) Others question if LCA can be truly value free, and propose various solutions to solve conflicts that are basically rooted in differences in perspective.^(5–7)

In this article, I will show the results of an historical/sociological analysis of debates about risks related to toxic substances. Chlorine in the Netherlands and PVC in Sweden will be used as cases. I will argue that three evaluative paradigms can be distinguished between which no choice can be made on the basis of scientific arguments alone. I will review various suggestions about how RA and LCA could deal with this “frame conflict.” Finally, I will show how within RA and LCA an alternative indicator system can be set up that honors the views behind the alternative frames, particularly what I call the precautionary frame.

2. FRAMES IN THE TOXICITY CONTROVERSY

2.1. Introduction

The experience in the last decades shows that RA and LCA have been only partially successful in ending controversies on toxicity risks related to substances such as chlorine and PVC.

Particularly during the 1990s, these materials have become “symbols” or “spearheads” in these debates for stakeholders such as environmental pressure groups and industry federations. As a consequence, many elaborated studies have been performed on chlorine and PVC over the past decade in various countries. However, these did not lead to consensus on the question of whether these materials fit in a sustainable society.^(8–11) Part of this is due to the fact that the knowledge to judge environmental impacts in complex cases is not yet robust enough—in major LCAs and RAs, uncertainties of a factor of 1,000 in toxicity scores were no exception.^(7,12) However, policy scientists argue that the ongoing controversy has to do with problems other than “scientific” uncertainty alone. For decades, these scientists have been indicating that such lasting controversies are rooted in the fact that different actor coalitions in society apply different basic evaluative philosophies, or “frames,” to analyze a situation.^(13–15)

Therefore, an in-depth argumentative analysis of the controversies on PVC in Sweden and chlorine in the Netherlands in the 1980s and 1990s was made.⁽¹⁶⁾⁴ Such an analysis provides an insight into how the

⁴ The argumentative analysis is too lengthy to reproduce here. Reference is made to the author’s book *Frames in the Toxicity Controversy*, published in 1999 by Kluwer Academic Publishers.⁽¹⁶⁾ That book gives an analysis of the chlorine and PVC debate in Sweden and the Netherlands, both based on extensive studies aiming to structure the debate as much as possible making use

controversies actually developed, what arguments played a role, and if these arguments changed over time. But more important, it gives a clear insight into the overall perspectives of actor coalitions with regard to toxicity problems, and the extent to which tools such as RA and LCA can appropriately serve as referee.

2.2. The Three Basic Philosophies or “Frames”

This analysis showed that in the Netherlands three actor coalitions could be discerned: environmentalists, the industry, and the environmental ministry. In Sweden, the same actor coalitions played a role, but instead of the environmental ministry, there was the Swedish EPA and the Swedish National Chemicals Inspectorate (KemI). Additionally, in Sweden some politicians formed an actor coalition of their own.

In the chlorine and PVC case, framing appeared to play a key role. Under their flexible, easily visible pragmatic rhetoric and tactical behavior, it appeared that different actor coalitions have different, very stable, and inflexible underlying “philosophies” about what they consider as an ideal, sustainable world.⁵ Three different philosophies or frames for assessing the sustainability of substances could be identified that were used by the seven actor coalitions discerned. Table I gives short descriptions of these positions, which I have coined the *risk assessment* frame, the *strict control* frame, and the *precautionary* frame. In essence, these frames implicitly disagree fundamentally on the following points:

1. The extent to which mankind truly has enough knowledge about the emissions and effects of substances on humans and ecosystems to avoid major future surprises.
2. The extent to which complex technical and organizational measures to close substance chains and to prevent emissions will work as intended.
3. The extent to which nature is resilient enough to deal with the consequences of any misjudgment related to points (1) and (2).

of natural science, as well as an analysis of the controversy from a more science-philosophical and politicological point of view.

⁵These levels correspond with, e.g., Fischer’s first-order and second-order arguments, or Sabatier’s secondary aspects and deep normative core.^(15,36)

Fig. 3 positions the problem analysis and preferred management solution of the three frames in the emission chain. In brief, people adhering to the *risk assessment frame* believe that knowledge is adequate, that emission control will work, and that nature is rather resilient. Hence, they accept in full a management model where emission-effect calculations are used to assess a possible danger, and in which emission reductions are adequate to bring them below the danger line.⁽¹⁷⁾ In this view, the chlorine industry is fully acceptable since for the most important chlorinated pollutants, risk assessments show that risks are limited or controllable.⁽¹⁸⁾ Adherents of the *strict control frame* acknowledge that insights about “safe” levels often have to be adjusted.^(19–21) Particularly for substances with inherent dangerous properties, and that can contaminate the environment irreversibly, strict control frame adherents tend to embark on a stringent emission control policy, regardless of whether currently accepted risk levels are exceeded. Adherents of the *precautionary frame* disagree that there is sufficient knowledge to allow relying on the former approaches in the first place. Hence, they judge substances primarily on indicators reflecting factors such as their inherent safety, the chance that ignorance is at stake, and reversibility of contamination (which allows the correction of wrong judgments). With regard to the chlorine industry, these adherents point at various elements that usually play no role in RA. They stress that over 80% of the volume of organochlorines found in nature cannot be identified and that their source is not clear.⁽²²⁾ They also bring to the fore that new classes of persistent organochlorines, with unpleasant properties similar to, for example, PCBs, are still discovered in the environment. Furthermore, they point at the fact that chlorine is reactive, and that in various processes in the chlorine industry many byproducts are formed.⁽²³⁾ Combining all this information, they fear that it *might* be the case that mankind is still “poisoning the environment” irreversibly by emissions of organochlorines from unknown industrial sources. Given their preference for precaution, they find this enough of an argument to prefer the use of alternative materials.^(24,25)

2.3. A Reflection on Incommensurability and Generic Validity

Advocating the idea that there is more than one well-thought-out way of evaluating toxicity threats is not uncontroversial in itself. First, an actor coalition often does not like to hear that its line of argument is

Table I. A Description of Frames in the Toxicity Controversy⁽¹⁶⁾**The Risk Assessment Frame**

The *first* frame broadly follows the classical risk assessment approach. It is therefore called the *risk assessment* frame. It is adopted by the industry in Sweden and the Netherlands and also to a large extent by the Dutch authorities. In terms of *problem analysis* this frame basically believes that the whole emission-effect chain can be analyzed and that meaningful assessments of final effects are possible.

Information on emission volumes, fate-related properties, and toxic properties of a substance is used to calculate a *prediction* of likely effects. In terms of *management solutions*, the approach is to reduce such effects (or better, the effect scores) to a certain threshold. In sum, predicted effects on species and ecosystems are used as a starting point for managing toxic substances. This frame reflects:

- a high degree of confidence in the capability of mankind to acquire adequate knowledge about emissions of substances, their fate, and effects;
- a high degree of confidence in technological emission reduction measures and in flawless, skilled behavior of the people who manage these systems;
- a high degree of confidence that nature can cope with the consequences of errors made by man in assessing the effects of substances and managing emission abatement technologies.

The Strict Control Frame

The *second* frame acknowledges that risk evaluations have limitations. It is adopted by the state agencies KemI and EPA in Sweden.⁽²⁶⁾

In terms of *problem analysis*, this frame is sensitive to the possibility that concentrations that are currently regarded as “safe” may be severely in error. This frame also uses information on emissions, fate, and toxicity in problem analysis, but in a different manner than this information is used in the risk assessment frame. In particular, by using fate information (derived, for example, from biodegradation tests and octanol-water partition coefficients), adherents to this frame discern three groups of substances, classified according to uncertainties in effect assessment. Substances that are not readily biodegradable and that are alien to nature are viewed as the most sensitive category. These substances have a long lifetime in the environment so emission of them leads to irreversible contamination. Errors in risk estimates can hardly be corrected by reducing emissions. Such corrections can much more easily be made for substances that are alien to nature but that are readily degradable. Finally, substances that are also naturally produced form the least sensitive category. In terms of *management solutions*, naturally occurring substances may be emitted up to a level that depends on the natural background. For degradable, nonnatural substances, a risk assessment approach is still acceptable. But persistent substances should be kept out of the environment. Since this frame is firmly based on a belief in the technical and organizational feasibility of maintaining substances in closed loops, its adherents opt for a strict minimization of emissions of such substances (rather than phasing them out). To sum up, adherents of this frame choose emissions from the production-consumption chain as a starting point for substance management. I therefore call it the *strict control* frame. It reflects:

- a moderate to high degree of confidence in the capability of mankind to gain adequate knowledge about emissions of substances, but low confidence in the ability to acquire knowledge about their fate and effects;
- a high degree of confidence in technological emission reduction measures and in flawless, skilled behavior by the people who manage these systems;
- a moderate degree of confidence that nature can cope with the consequences of errors by man in assessing the effects of substances and managing emission abatement technologies.

The Precautionary Frame

The *third* frame assumes that risk evaluation is too weak a basis for management of toxic substances. I call this the *precautionary* frame. This frame is adopted by the environmental pressure groups in the Netherlands and Sweden, as well as by influential politicians in Sweden. In terms of *problem analysis*, it tends to classify substances in the same way as the strict control frame. However, the precautionary frame is even more pessimistic about the feasibility of effect assessments. For example, the issue of endocrine substances convinced Sweden’s Chemicals Policy Committee⁽¹⁹⁾ that toxicity assessments are so fallible that toxicity is not a useful criterion in substance policy. The analysis concentrates on identifying substances for which this lack of knowledge seems most important and making use of all possible information sources, for example, indications that important amounts of byproducts are formed in a process, or the unexplainable occurrence of substances in nature that belong to the same group, are seen as an additional reasons for suspicion. So this frame, too, uses information on emissions and fate, but differently from the other two frames. Rather than the quantitative effect calculations favored by the risk assessment frame, the precautionary frame adopts a more qualitative, descriptive analytical framework, making quite holistic use of the available information. In terms of *management solutions*, this frame is pessimistic about the practical effectiveness of control measures. A preventive and precautionary approach is preferred, which implies a choice in favor of alternatives that are inherently safer (in terms of known toxicity problems and potential uncertainties). In particular, the emissions of persistent and bioaccumulative substances should be completely stopped. This goal should be realized by a phase out, since all materials handling implies that the material sooner or later ends up in waste, or will be directly released into the environment. This is a management scheme that is concerned with the *production processes* themselves. It reflects:

- a low confidence in the capability of mankind to gain adequate quantitative knowledge about emission, fate, and effects of substances, and a preference for a rather holistic, qualitative, evaluative approach;
- a low degree of confidence in technological emission reduction measures and the idea that we can never expect people to commit no errors;
- a low degree of confidence that nature can cope with the consequences of errors by man in assessing the effects of substances and managing emission abatement technologies;
- hence, a strong preference for inherently preventive and precautionary options.

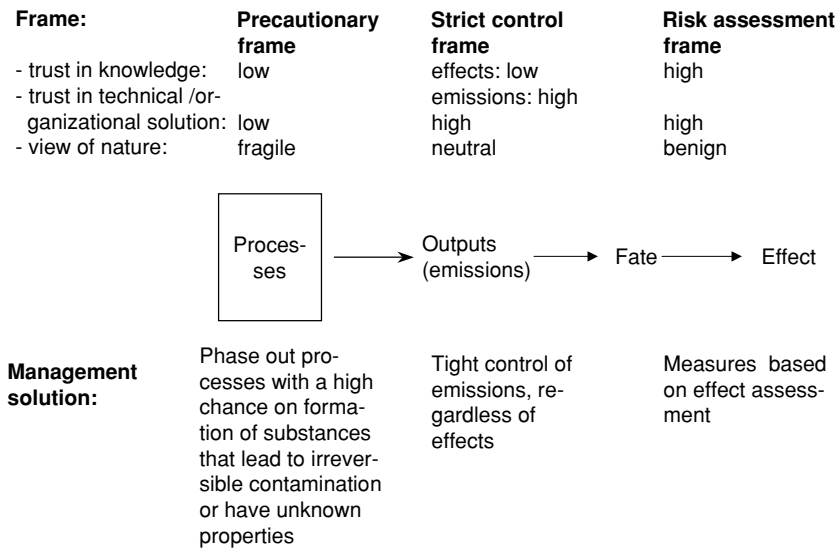


Fig. 3. The frames positioned in the emission-effect chain.

not the only sound or reasonable one.⁶ Second, this position has important implications for the way science (and scientists) can play a role in policy making, implications that do not always fit with existing institutional arrangements, positions, and habits.⁷ And third, it goes contrary to the common-sense perception that the natural world could embody two or three analytical “truths” rather than just one.

From a scientific viewpoint, only the third issue is relevant. As already indicated in Section 2.1, modern philosophy of science and policy science have little problem with accepting that in complex situations there can often be several plausible (incommensurable) readings at stake. In my view, the existence of such different frames should not be equivocated with different “true worlds.”⁸ The point is that complex is-

ssues like toxicity cannot be so fully and unequivocally characterized by science as, for instance, simple problems like calculating the time it takes a brick to fall from the top of the Empire State Building. To come to overarching statements about the acceptability of certain chemical industry sectors, or even substances, actor coalitions necessarily have to frame the bits and drabs of undisputed knowledge, which generally only make up a limited part of the puzzle, into a full picture. My only claim is that different actor coalitions do this in different ways, and that it is difficult or impossible to reject any of these different ways decisively as nonfactual, untrue, implausible, or the like.⁹

The three frames shown above were derived from case studies on chlorine and PVC but they probably have general value. Industry backs the risk assessment approach worldwide for substances in addition to chlorine or PVC.⁽¹⁷⁾ Swedish EPA and KemI

⁶ Indeed, who is worthy of being labeled as “scientific” is one of the fierce points of debate. Quite a few adherents of the risk assessment frame frequently call their approach one of “sound science,” and have less-flattering adjectives for the science of their adversaries. Adherents of the precautionary frame, in contrast, reject the “sound science” that calls for incontrovertible proof between cause and effect as an “unreasonable standard in policy making” on toxic substances,⁽³⁷⁾ or simply “foolish,”⁽³⁸⁾ and call for a more precautionary “good science.”⁽²⁵⁾

⁷ For instance, current methods of RA and LCIA largely follow the risk assessment frame, and thus cannot be labeled as neutral tools. Also, the strict division between risk assessment (often positioned as neutral, science-based) and risk management (where policymakers should have the lead) cannot altogether be maintained anymore.^(39,40)

⁸ The interpretation of philosophy of science given here is necessarily limited and incomplete. I refer to authors such Kuhn,^(13,41) Hoyningen-Huene *et al.*,⁽⁴²⁾ and Jasanoff *et al.*⁽⁴³⁾ for much better elaborated analyses of both terminology and content, or to

my aforementioned book for a discussion in relation to decision making on toxic substances.⁽¹⁶⁾

⁹ Some authors argue that risk assessment and precaution in principle do not need to be opposing entities, and that both try to embrace the best elements science can offer. The precautionary principle tries to draw proper attention to elements of ignorance and uncertainty, and acknowledging ignorance and uncertainty is one of the key issues in good scientific practice. Risk assessment already covers certain precautionary elements, such as safety factors, to deal with uncertainty, and there is probably no fundamental reason why risk assessment could not include other elements of ignorance and uncertainty in its evaluative procedure.⁽⁴⁴⁾ The problem is, of course, that in the view of the adherents of the precautionary frame under the current institutional arrangements and practices, risk assessment is executed in a rather reductionist way, leading to ignorance of ignorance.

developed their strict control approach as a generic policy for manmade, persistent, and bioaccumulative substances. The precautionary philosophy already plays a role in various discussions on substance policy in general in, for example, Sweden, the United Kingdom, and the European Union.⁽¹⁹⁻²¹⁾ Recently, Thornton,⁽²⁵⁾ a former Greenpeace scientist, developed a book-length argument for basing substance policy on what he called an “ecological paradigm”¹⁰ rather than a “risk paradigm.” Finally, the risk assessment frame, strict control frame, and the precautionary frame correspond well with more generic anthropological theories, particularly the individualist, hierarchist, and sectist biases from cultural theory. This theory was developed by Douglas, Wildavsky, and Thompson, and claims to have identified a limited set of cultural biases that are valid for all times and in each society.^(27,28) Hence, it is plausible that the three frames presented here can serve as ideal types of positions for actor coalitions in debates on toxic substances.

3. DEALING WITH FRAMES: TOWARD PRECAUTIONARY INDICATORS

3.1. Introduction

How can RA and LC(I)A deal with the existence of framing in the toxicity debate? The following strategies have been proposed.

1. *Standardization.* An authoritative forum is established that makes explicit choices on all points on which frame conflict exists, which leads to a uniform method.
2. *Stakeholder deliberation.* The practitioner acknowledges the fact that he or she and/or his or her method may be biased. He or she tries to become truly aware of the mainstream stakeholder views by interviews, literature analysis, etc., and writes an interpretation that honors these views as far as logic allows it.
3. *Participation.* More participatory forms of RA and LCA are developed that allow for learning processes between societal groups with different biased views, resulting in a more balanced, and thus better and more societal-accepted, evaluation.⁽⁶⁾

¹⁰Since Greenpeace played an important role in the cases I analyzed, Thornton’s extensively elaborated ecological paradigm is of course what I tried to describe in my own way as the precautionary frame.

4. *Modeling frames.* The inevitable subjectivity in RA and LCA method is acknowledged by developing multiple indicator systems that reflect the views of the most important societal actor groups.

The first approach is often found attractive but has a clear danger. Such an authoritative forum will inevitably overrule the pluriformity that is necessarily at stake if science lacks robustness. This is not only a problem from a democratic viewpoint.⁽²⁹⁾ More important, by using such a method, policy advisers and scientists will most probably stay unaware of the fact that the pluriformity of basic views plays the key role in the controversy or problem they want to solve.¹¹

Various authors have published about the second and third approaches.^(30,31) As for the fourth approach, current methods of RA and LCA fit obviously quite well with the risk assessment frame. Indicator systems related to the other two frames, however, are lacking. In the next sections, I will contribute to the fourth approach by giving an outline of a possible indicator system related to the most extreme frame, i.e., the precautionary frame.¹²

3.2. Ignorance and Irreversibility as Key Issues

As indicated in Section 2, the adherents of the precautionary frame have low trust in the adequacy of our knowledge, low trust in complex technological and organizational measures to keep substances in closed loops, and believe that nature is fragile. From this attitude it follows that an indicator system needs to address the following two issues explicitly.

1. The extent to which ignorance and potential surprise could be at stake.
2. The extent to which activities allow for learning by doing (i.e., it must still be possible to

¹¹Note that this solution also assumes that all elements in the frame conflict can be made explicit as if they were value choices, a point that is often questioned in philosophy of science and policy science.

¹²Some authors, based on cultural theory, have already elaborated multiple indicator systems.^(5,45,46) However, these systems do not always include toxicity problems, or, since they take cultural theory as a starting point, do not always cover the elements of ignorance and uncertainty that appear to be relevant for the adherents of the precautionary frame in my cases. For instance, in his extensive cultural-theory-based LCIA system, Hofstetter⁽⁵⁾ varies mainly the relevance/weight of the bioaccumulative properties of substances and the classification of substances as carcinogenic or noncarcinogenic. These are just two of the elements that, according to Section 3.3., form the crucial differences between the risk assessment and the precautionary frame.

reverse judgments made now, but that appear to be wrong in future, before major, irreversible damage is done).

Below, following the emission-effect chain that forms the core of traditional RA and LCIA, I indicate which elements reflect ignorance and irreversibility.¹³

Emissions from Processes/Substance Chains

1. *Formation of unknown byproducts and emission of unknown substances.* Certain processes in the chemical industry (e.g., when chlorine is used in a reactive form) are more likely than others to produce byproducts. Such byproducts might be emitted unconsciously at the production plant or be released from the product. More generally, it is possible that emission inventories used as a basis for RA and LCA do not cover all substances that are relevant in a toxicity evaluation. Emission-monitoring systems usually focus on the main raw materials and products in a chemical production process.¹⁴
2. *Complex emission control and substance chain management might not work flawlessly.* The more complicated emission control and substance chain management becomes, the more chance there is that their effectiveness is low or that unexpected surprises might occur. For instance, it is well known that systems for the collection of small quantities of hazardous substances don't cover dozens of percents of the theoretical quantities. More fundamentally, the system can be analyzed only in a traditional way if certain assumptions are made about human behavior and technical performance that "fix" the system. This neglects the social underdeterminancy and path-dependency that is involved. As particularly shown by Wynne,⁽³²⁾ over time historical developments and developments in human behavior patterns can lead to surprises never anticipated by those who initially did the risk

¹³ I chose not to take formal definitions of the precautionary principle as the basis for this article. Lack of information/ignorance and the potential for irreversible damage form key elements in such definitions, however.⁽³⁸⁾

¹⁴ Not covering byproducts from the chlorine industry was one of the main points of concern of the peer-review commission on the Dutch chlorine chain study.^(11,47)

assessment or designed the risk management system.¹⁵

Fate

3. *Input data for the fate model are uncertain or unknown.* This is the classical data uncertainty that is taken into account in the more advanced approaches to RA and LCIA.¹⁶ For many substances, many parameters needed in a proper risk assessment have not been measured or determined, or are only known with large uncertainty (e.g., they had to be estimated with QSARs, etc.).¹⁷
4. *The fate model does not cover all relevant pathways.* Ecosystems are very complex and fate models necessarily have to limit themselves in the number of pathways they can cover. This leads to the criticism that models might miss potentially relevant pathways, relations, exposure situations, etc., and that the final analysis is blind for the complicated cascades and feedback loops that are present in the ecosystem.⁽²⁵⁾
5. *Degradation products are not included.* RA and LCIA tend to concentrate on the primary substances that are emitted from the system analyzed. In nature, substances are degraded and produce decay products. It is not always clear which decay products are formed. For some substances, such decay products can cause risks as well.

Effect

6. *Effect data for known endpoints are uncertain or lacking.* Like the first point mentioned under *Fate*, this is a classical form of data uncertainty. Although industry in the United States and Europe has committed itself to generate at least a screening information data set (SIDS)

¹⁵ For instance, not many persons would have thought that it would ever be possible that dioxin-contaminated transformer oil would find its way into chicken feed, leading to the Belgian chicken meat crisis in early 2000 and an unprecedented exposure of humans to dioxins.

¹⁶ It must be noted that in many cases the sensitivity analyses performed cover only part of the data uncertainties, and limit themselves to probabilistic methods that do not take into account systematic data uncertainties (compare van der Sluijs⁽⁴⁸⁾).

¹⁷ Various sources indicated that by around 1998, even for the 2,000 high production volume chemicals, in only some 5–15% of the cases was a complete screening information data set available.^(49–51) The European Inventory of Existing Substances (EINECS) lists some 100,000 chemicals, of which several 10,000 are believed to be commercially produced.

in the next few years for the high production volume chemicals (HPVCs), it is unlikely that this will solve this data problem. In practice, standard setting for TDIs and NOAECs appears to be a difficult process, and the final values agreed upon rarely reflect the high uncertainties dealt with during the process.¹⁸

7. *Yet unknown endpoints may be at stake.* Current standards are based on known effect endpoints. However, it cannot be excluded that new, relevant endpoints will prove to be relevant in the future. Indeed, adherents of the precautionary frame find a system that concentrates on a limited number of types of effect endpoints, evaluated via animal testing at, in general, high doses, uncaringly crude—given the incredible complexity of ecosystems, the human body, and the development processes that take place therein—in relation to the limited number of elements that are truly fully understood. In this respect, Colborn *et al.*⁽³³⁾ saw the emerging issue of endocrine disruption as evidence that “humanity is flying blind.” The Swedish Chemicals Policy Committee found this an argument that (known) toxicity problems should not be the primary basis for policy making about toxic substances anymore.⁽¹⁹⁾
8. *One-by-one substance evaluations related to single species do not reflect what happens in the real world (exposure to mixtures, exposure in a certain context, etc.).* This might be one of the most controversial objections to the current RA and LCA approach, since it questions whether traditional animal testing leads to useful knowledge at all. In the real world, exposure takes place to mixtures of chemicals, and individual species are part of an ecosystem with all kinds of still unclear feedback loops. Some do not exclude that a chemical ingested at low doses in a certain context might lead to no harm, whereas ingested in another context or in combination with other chemicals, it will.¹⁹ It is also argued that the focus on

individual species neglects that ecosystem integrity depends on the interplay of species, and that thus the whole system has to be judged. Indeed, this point and point (7) above reflect that the precautionary frame takes a fundamentally different attitude with regard to analyzing toxicity threats than does risk assessment. The precautionary frame starts from the assumption that the chemicals that currently exist in nature are there as a result of a natural development and selection process of millions of years and, hence, with good reason. Others were not produced in this process and thus are thought to be absent for a very good reason. It is thus seen as very logical to regard every human-produced chemical *a priori* as suspect, potentially incompatible with the current, complex machinery that forms our ecosystem until proven otherwise. The difference with risk assessment, which assumes *a priori* that there are acceptable contamination levels for a substance regardless its origin, is obvious.

3.3. Toward Indicators

How can the elements reviewed in Section 3.2 be translated into indicators that say something about the (potential) level of ignorance, and the level of (ir)reversibility of contamination and effects? Below is a proposal in which indicators related to the properties of the system analyzed and the substances emitted could play a role. Indicators could include the following.

First to be considered are system-related indicators. System-related indicators mainly have to show the possibility that ignorance about the type and volume of emissions is at stake. Such proxies for ignorance about emissions could include:

- *In the processes subject to evaluation relatively high percentages of byproducts are formed.* This indicator could be expressed in terms of the percentage of unexpected byproducts formed in the process.

¹⁸In the words of Jasanoff:^(39:234) “That such constructs [toxicity standards—AT] sometimes break down under political pressure is hardly surprising. Their frequent durability is the greater puzzle.”

¹⁹This is, in fact, an alternative interpretation of research by Ames *et al.*⁽⁵²⁾ Ames *et al.* showed in a series of articles that natural substances present in, for instance, foodstuffs, have about the same positive scores in animal cancer tests as manmade substances. In

the view of Ames *et al.* this suggests that the large number of such “natural carcinogens” might be a far greater health problem than the relatively small volumes of synthetic chemicals. Others see such findings rather as evidence of the crudeness of cancer testing, or that apparently the molecular context in which chemicals are ingested might be crucial, etc.^(53,54)

- *Managerial complexity of emission control and chain management is high.* This aspect probably best can be covered by an ordinal indicator, combined with a classification and ranking of processes by expert judgment.
- *For the processes subject to evaluation there are various indications of unknown emissions.* Often, there are other indications if a process is likely or not to generate yet unidentified emissions. Rather “hard” indications of the presence or absence of such unknown emissions could be obtained via total effluent monitoring tests, comparing monitoring results on the basis of sum parameters and individual substances, etc. Experience from the past also can give an indication if the processes subject to evaluation are likely to generate unexpected emissions.

The second set of indicators are substance related. The substance-related indicators mainly have to show the possibility that ignorance about fate and effect is at stake, or that irreversible contamination of nature may occur. Proxy indicators for these elements could include:

- *The substance subject to evaluation belongs to a class with high, unexplained concentrations in the environment.* In some cases, there is a large difference between the sum of concentrations of substances covered by environmental monitoring programs, and the concentration reflected by a sum parameter for the substance group.²⁰ This suggests ignorance about fate and emissions for substances belonging to this group. This information could be translated in an ordinal indicator (e.g., probably no, medium, high difference).
- *For the substance subject to evaluation, fate and effect data are incomplete/uncertain.* The classical data uncertainty can be covered by classical uncertainty analysis (e.g., Monte Carlo analysis based on a realistic variation of values). Since the indicator system is intended to reflect the precautionary frame, one could consider including a precautionary bias in the analysis.
- *The substance subject to evaluation has persistent and bioaccumulative properties.* Sub-

stances with persistent and bioaccumulative properties tend to have long lifetimes in the environment and it is likely that they will be dispersed via more unexpected pathways, which might be the case with other substances. Furthermore, contamination of the environment is relatively irreversible. If, for some reason, “safe” levels appear to be lower than originally thought, this cannot be corrected on short notice by emission reductions.²¹

- *The substance subject to evaluation belongs to a class with a relatively high risk of formation of unknown decay products.* If research has been done into decay products, of course these themselves can be included in the analysis. However, in many cases, only sketchy information might be available, and judgment may have to be made on such information, the structural formula of the compound, etc. This aspect probably best can be covered by an ordinal indicator, combined with a classification and ranking of processes by expert judgment. This indicator is a proxy for fate ignorance.
- *The substances subject to evaluation are purely manmade/synthetic.* To some extent, one could argue that for natural substances problems such as ignorance about unknown endpoints and the relevance of animal testing are less relevant than for purely synthetic substances. After all, the former have been present in nature and management can be concentrated on preventing the sheer volume of anthropogenic emissions from leading to high additions to existing natural background concentrations.

This list does not give a clear-cut calculation scheme that allows for determining a comparative assessment of toxicity problems according to the precautionary frame. Most of the indicators proposed can be seen as proxies for system (emission) and substance (fate and effect) related ignorance and irreversibility. They could be used to give a bonus/malus score to the emission and fate/effect elements that are used to calculate RA or LCIA scores in the traditional way, leading to “precautionary” adaptations of the values of e_i , f_i , and I_i in Equations (1) and (2). But the importance of the ignorance and irreversibility made visible in this way, let alone the weight that ignorance

²⁰ For instance, the earlier-mentioned difference between the volume of extractable organic chlorine (EOCl) in media like fish fat and sediments, and individual chlorinated compounds measured during normal monitoring.

²¹ Probably the best example are CFCs. Even with the current total ban on production, CFCs emitted in the last decades are still present in the stratosphere, with the consequence that it will take decades before the ozone layer can fully recover.

and irreversibility should be given, can hardly be assessed neutrally.²² This is a job that should take place in consultation with the relevant stakeholder groups, and for the time being this proposal can be used only as a checklist. For instance, if in a comparative RA or LCA, emissions from two different substances end up with the same “traditional” effect scores, but for one of the systems the above-mentioned precautionary indicators score is, in general, worse, one could argue a preference for the other substance.

4. CONCLUSIONS

To sum up, this article claims that in comparative toxicity assessments framing exists and is here to stay. Adherents of the risk assessment frame, strict control frame, and precautionary frame have all made sense of the world in a reasonable way. If tools such as classical RA and LCA are used, which are predominantly shaped according to one frame, these tools can play only a limited role in giving decisive information in comparative assertions about toxicological risks.

One of the options is to develop fate and effect models that explicitly deal with the elements of ignorance and irreversibility that are regarded as crucial by the adherents of the precautionary frame. However, miracles cannot be expected. Even traditional comparative assertions based on classical RA and LCA are characterized by high uncertainties. As indicated above, a factor of 100 to 1,000 of difference in effect score due to uncertainty in input data alone is not unusual.^(2,7)

If, additionally, model uncertainty and the uncertainty related to framing differences is taken into account, this gives a not too optimistic picture about the potential of purely “scientific” methods to give final answers about relative toxicity risks. That framing uncertainty must be taken into account in the use of RA and LCA is, in my view, without doubt. However, I expect that the main value of applying even such extended tools lies in *structuring* debates on relative risks rather than giving *answers* in such debates.

Which frame will dominate and shape substance policy in the future is, of course, uncertain. Cultural theory claims that the only certainty is that such bi-

ases will alternate.⁽²⁸⁾ This would suggest that it would be wise for the chemical industry to treat varying societal demands with regard to the safety of human-made substances as one of the strategic uncertainties they have to deal with. In essence, such problems are nothing new for industry. Traditionally, industry has faced similar long-term strategic uncertainties with regard to available technologies, the sociopolitical environment, and market demands. Indeed, many industries are already used to applying methods such as scenario development to identify robust strategies that deal well with these uncertainties. Therefore, I think that for industry there is a clear value in specifying and operationalizing the elements of the precautionary frame. This will allow industry to identify rather easily the types of substances they produce that will, with reasonable likelihood, give rise to debate between the adherents of the risk assessment frame and those of the precautionary frame.

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²² However, to some extent, quantification may be possible. Usually, a rough idea about the maximum mass flow of the unknown emission can be obtained. If the substance belongs to a group for which no high, unexplained concentrations in the environment are at stake, the problem of unknown emissions probably is low. The problems described might particularly be at stake for the fate and effect elements.

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