Good Scientific Practice in Industrial Ecology

A Factsheet

Compiled by Stefan Pauliuk, including input of different colleagues, cf. acknowledgements below

Version of July 2024

Goal: *Provide researchers and students with a condensed overview of three main aspects of good scientific practice in industrial ecology: research ethics, best practice for conducting and documenting research, and research tools.*

Topics covered:

1) Research ethics overview. Core scientific principles and good scientific conduct.

2) Best practice for carrying out, documenting, and publishing research: including recommendations for report structure and scientific writing as well as reproducible research.

3) Some state-of-the art tools and infrastructure for IE research.

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1. Research ethics

Science is a self-governed enterprise. The rules of knowledge creation are established and enforced by the different scientific communities themselves, with little interference from the outside. Scientific knowledge creation follows a number of core ethical principles, and it is the duty of individual researchers to apply these principles in their work and of scientific communities to assist researchers in doing that by providing additional guidance:

Here, I refer to a list of six principles of science ethics and further explanations compiled by Israel's National Council for Research and Development, which I found particularly comprehensive and applicable to IE research [1]. I rephrased some of the explanations to better fit the scope of IE research.

The ethical principles of science apply to all forms of research – whether in academic, industrial, or governmental settings – and to all scientific disciplines.

- **Truth**
    - Strive to expand the human knowledge of the world and of sustainable development, in particular.
    - Deepen human understanding of the various aspects of sustainable development and the systemic approach.
    - Enhance human ability to exploit that knowledge.
    - Serve the above goals by acting in accordance with the methods of industrial ecology and the rules of good scientific conduct in general.

- **Freedom**
    - Scientists serve goals of scientific research based on the principle of scientific freedom, which states that scientists must be able to work free of political, religious, or other external influence to pursue the goal of objective knowledge generation.
    - Scientists comply with the ethical restrictions resulting from scientific freedom for the adequate safeguarding of life, welfare, dignity, and liberty. Not all research problems that can technically be explored are socially acceptable.

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- **Responsibility**
  - Scientists bear full responsibility for every scientific experiment they conduct.
  - They take into consideration the lives and welfare of animals being used in scientific research.
  - They take into consideration that the results of their research may be used to attain goals within a wide range, including criminal uses.

- **Integrity**
  - Scientists perform every scientific act in accordance with all requirements of the scientific method applied, and work at the highest standards.
  - Scientists analyse data and make generalisations with depth and precision:
  - Scientists present their data in full, precisely, frankly, and fairly.

- **Collaboration**
  - Scientists act within a universal framework of scientific collaboration based on the shared scientific goals.
  - Scientists foster collaboration by maintaining an atmosphere of openness, mutual assistance, and trust.
  - Scientists merit individual, collective, and institutional credit.

- **Professionalism**
  - Scientists engage in their pursuits in a wholly professional manner, continuously applying their special knowledge.
  - Scientists strive to keep abreast of developments in their area of expertise.
  - Scientists make ethical decisions based on the values and principles of scientific research.

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Another good orientation is the compilation **"On Being a Scientist – A Guide to Responsible Conduct in Research"**, issued by The National Academies Press (2009) [2]. It describes the ethical foundations of scientific practices and some of the personal and professional issues that researchers encounter in their work.

Also, many universities and research institutes have their own guidelines. The main stipulations can be summarized as follows:

- **Be aware of the ethical aspects of scientific work**
- **Work in accordance with accepted rules ("lege artis")**
- **Document your research findings**
- **Show honesty toward the work of partners, rivals, and predecessors**
- **Avoid academic misconduct and take precautions to prevent it**

What does that all mean in practice? Sure, there are examples of severe forms of scientific misconduct, and the NAP brochure lists some examples, where entire experiments were faked, for example. In those cases, the consequence is often expulsion from the scientific community. The ethical problems that occur in practice are of a different kind, however. According to my experience, they fall into three categories and can be dealt with as follows:

- **Biased research**
  - When normative aspects prevail, system boundaries can be tweaked, or complex results must be simplified to be reportable, there is a chance that research results reflect the perspective of the funder. That problem is pervasive in LCA, due to lacking open data.
    - Always state the funding source and declare potential conflicts of interest!
    - Decline consultancy jobs if scientific freedom is not guaranteed!

- **Sloppy work and documentation**
  - Results of scientific work must be reproducible, meaning that documentation, tools and other scientific records have to be kept.
    - Strive to diligently document the different steps of your research!
    - Document data gathering, data analysis, and result extraction in a way that allows others to reproduce the work done (and ideally build upon and improve it)!

- **Publication standard and plagiarism**
  - "Plagiarism is the wrongful appropriation and stealing and publication of another author's language, thoughts, ideas, or expressions and the representation of them as one's own original work."
    - Properly cite and acknowledge ALL work (data, methods, results, conclusions) that are used in your own work and publications!

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2. Good scientific practice in industrial ecology

2.1. General guidelines

+ Work towards high standards of data and procedural transparency. In particular, the guidelines for open data issued by the International Society for Industrial Ecology need to be followed (https://is4ie.org/data). The source of all data used, all assumptions made, as well as all major steps of the subsequent analysis needs to be documented so that researchers not involved in the original work can understand the procedures taken and replicate the scientific claims drawn from the work. If figures are published as part of reports and papers the numerical values of the variables plotted in the figures need to be supplied in tabular form in the supplementary material.

+ Develop a professional workflow including regular backups, archiving of results, and dissemination of finished work. Ongoing work needs regular backups, at least once a week. Finished projects need to be archived in electronic form in a convenient repository. The archived data and procedures shall be comprehensive so that other researchers can trace the data and methods to their original respective source and to replicate the analysis.

+ All raw data (or static links/identifiers to them), software scripts, and other models (incl. Excel files) that were part of the work need to be archived. Researchers should make an effort to make the archived material useful for others, e.g., by providing written explanations for how to use the material. If work done by one scholar gets re-used by other group members or external colleagues, proper credit needs to be given.

+ Consider working towards open science: If license agreements, working contracts, or nondisclosure agreements do not dictate otherwise, the analysis software and workbooks and other modelling software should be developed in a manner that allows easy reuse by other researchers both within and outside the group. Modular software, script-based analysis, and open source software shall be developed, used, and supplied to the community whenever reasonable.

+ Keep your documentation, i.e., everything that is necessary to reproduce your result, in particular
- Lab records,
- Computer codes and output,
- Calculations,
- Data treatment and statistics

… for at least 10 years!

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2.2. Criteria for sound publications and their structure

A good paper/report has the following features:

I) Report sound, original and interesting research,

II) Necessary documentation and clear presentation

III) Fair credit to previous work

IV) Proper credit to those who have contributed, either in the author list or in an acknowledgement

Some more general tips for what characterises a publishable article and how to overcome the imposter syndrome:

https://www.insidehighered.com/advice/2019/07/18/how-write-publishable-journal-article-opinion

A good paper/report has the following structure:

Exceptions from this rule are possible, but the system below almost always works and should therefore be applied in most cases. Described by Julian M Allwood in personal communication in 2012 and amended by S.P.

Abstract: Problem and research gap statement, methods, main results and discussion items.

1. Introduction: (a) what is the problem and who cares? (b) what's been done in this area before? (c) why is previous work inadequate - what's the gap in knowledge that this paper addresses, what specific question(s) do we need to answer?

2. Methodology: exactly how have we gone about trying to fill the gap/finding an answer to this question(s)? If we had to make methodological choices, why was there a choice, and out of all the possible options, why was the choice we made the best one? In the supplementary information, there should be enough of the boring details that if someone elsewhere wants to recreate our results, they can do so as exactly as possible.

3. What results did our work, using the methodology of 2, provide in answer to the question(s) posed in 1? What are the main features of these results - ie what's big, what's small, and what stands out? The results section should have no opinions - and be purely evidence.

4. Discussion: How would a neutral, and slightly sceptical observer, evaluate our results? Have we completely filled the knowledge gap and fully answered the question(s) of 1? (I've never seen a paper achieve this.) If we didn't create a perfect answer, what features of our results are of most benefit, and given that we didn't provide a perfect answer, can we now revisit the question(s) from 1 to act as a guide to future researchers? Did we learn anything by accident that applies elsewhere?

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Conclusion: Briefly, what are the broad implications of the research presented? No extensive summary of the work, no new references, no new details.

Depending on the setup, it is possible to merge sections 3 and 4 into a combined results and discussion section.

2.3. Writing style, manuscript preparation and citation style

"Writing is the most common form of scientific communication, yet scientists have a reputation for being poor writers. Why? One reason could be that writing is never really taught to scientists. Better writing will benefit your science career in several ways. Within the scientific community, improved communication leads to improved collaboration, easier access to cross-disciplinary knowledge, and faster, less painful training. Besides this, you will be able to communicate better not only with other researchers, but with the public, who funds your research.

If scientists were better writers, the gap between the public and academy would shrink."

From https://sites.duke.edu/scientificwriting/

Many scientific fields have their specific writing style, which differ to some extent. Due to its diversity and young nature, Industrial ecology does not prescribe a certain style, and the spectrum of styles used is diverse.

Irrespective of the style chosen, all scientific writing needs to fulfil certain quality requirements, as explained here, for example: https://www.e-education.psu.edu/styleforstudents/c10_p6.html

A good paper/report has the following writing style:

Below follow some broad guidelines for scientific writing for industrial ecology. You don't have to be a native speaker to be able to apply them, rather, you should think of your writing skills as one of your most important tools that are at your disposal, and this tool can be improved and sharpened over time.

+ Scientific writing must always be clear: Write in a concise and descriptive manner. Use a clear sentence structure, a convincing logical argument, and avoid unnecessary phrases and grammatical constructs (concise). Deliver a descriptive presentation of the work done, try to create an exact imagination of what you did in the mind of the reader. A good explanation can be found here: https://www.butte.edu/departments/cas/tipsheets/style_purpose_strategy/writing_clearly.html

+ Check that there are sufficient logical linkages within and between sentences: Often, connections between sentences are so clear in the writer's mind that they seem unnecessary to state. Writers underestimate the difficulties and ambiguities inherent in the reading process. The more logical linkages the reader has to construct by herself the higher the chance that misunderstandings occur or the reader gets tired and loses focus. Guidelines for reducing logical gaps can be found here: https://www.e-education.psu.edu/styleforstudents/c10_p6.html

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+ Active voice should prevail, sentences should be short. Passive voice and long sentences can still be used, of course. If in doubt or several options seem to be good, go for the one with active voice and shorter sentences.

+ Consistent use of tenses: There are many rules to consider when choosing the right tense. Check the reports linked below for more details. At least, the tense in each section should be consistent. E.g., either write 'I chose to…', 'I assumed that' or 'I choose to', 'I assume that', but do not mix the two.

http://services.unimelb.edu.au/__data/assets/pdf_file/0009/471294/Using_tenses_in_scientific_writing_Update_051112.pdf

https://files-aje-com.s3.amazonaws.com/www/row/_assets/docs/AJE-Choosing-the-Right-Verb-Tense-for-Your-Scientific-Manuscript-2015.pdf

+ Engineer the sentence structure: Be aware of that there is a topical position (describe the context of something within your work) and a stress position (new fact) in the sentences you write.

For example: "When changing the electricity mix in the product system to XY (topical position, as the product and the electricity mix scenario were already introduced), the carbon footprint of the product changed by Z % (stress position: new fact)."

Or: "The recycling efficiency indicators for most countries decline (stress position) when obsolete stock formation is taken into account. (topical position)"

Some say: The most important part of the sentence should come first. (stress position)

while others say: Context should come first, then the new thing (topic position and stress position).

When writing the text, you have to decide about the order of topical and stress positions for each sentence. This represents a powerful tool for making your writing both readable and interesting. One broad guideline to follow is to use the order topical position first, stress position second for most sentences (good to read but a bit boring) and reverse the order for some crucial sentences only to direct the reader's focus to the core points.

+ Avoid jargon and informal language (jargon = abuse of technical language to conceal weak arguments). Stick to the scientific language of the field you're in. All other terms and phrases should be avoided and replaced by descriptive language or defined. A good example for jargon in industrial ecology are phrases like 'hybrid model' or 'bottom-up' study, which mean nothing and a lot of things at the same time. You always need to define what exactly you mean by these terms. That may be clear within your research group but to outsiders, it may be not.

+ Provide specific information wherever possible: A core characteristic of scientific texts is that they are as exact as possible. Often, qualitative descriptions can be replaced by more exact or even quantitative descriptions, like: 'in the majority of all cases' -> 'in 75% of all cases' or 'very large percentage' -> '89%'.

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The industrial ecology scientific writing quick fix table (with a bias on MFA research):

So, you've written up a great research piece and want the world to know about it. Great! Please be mindful of your readers and make your work accessible and understandable to them. Therefore: everyone, wherever you are and whatever you do: Before you submit/publish something in quantitative industrial ecology and socio-metabolic research, please make the following checks:

- Introduction: Cite major established findings (e.g., on energy use, climate change, resource use) from authoritative sources, reviews, and synthesis reports, such as the IPCC, IPBES, IEA, or the UNEP-IRP, not from individual papers.
- Methods: When using different colors in system diagrams, schematic drawings, and figures: If the meaning of the different colors is not completely obvious, explain the color coding in the figure's legend or caption!
- Methods and overall consistency: Check that your system definition/system boundary and choice of indicators matches your research question. Adapt your system definition to the different research questions if needed! Check that your display of results is done in a way that directly addresses the research question(s)!
- System definitions: In a proper MFA diagram, the trio material/region/time frame is always displayed. This also applies to process diagrams (box-flow drawings) of unit processes in LCA.
- Results: Plausibility-check the correct order of magnitude of all reported indicators (compare with national total production, waste flows, stocks, GHG, etc.)
- Results: In plots: Each axis is labelled with an indicator and a unit.
- Plots: Consider accessibility: try to use colors in a way that won't create problems for the many readers with some form of color blindness (for a good discussion and design suggestions).[1]
- Results: Link your numerical results to your system definition: E.g., "Fig. 4a reports the scenario results for flow F_6_7 (final consumption), Fig. 4b the GHG emissions of the use phase (scope 1, F_7_0)."
- Proper rounding of numerical results: if no error range is given, round to 2-3 significant digits. If you have an error range, round main result to the same precision as the error value rounded up to 1 or 2 digits precision.
- For time-dependent results: Always make clear (in text, indicator label, and unit) whether you report annual (for which year?) or cumulative (for which time range?) values. Annual values come as amount/yr, cumulative values as amount.
- General: Check all instances where you report changes (absolute or in %): Is the reference value clear? (E.g., "Indicator x improved by 5%. -> 5 % compared to what?)
- Check that you use % when you report a relative change of a value in any unit and pp (percentage points) when you report an absolute change of a % value.

[1] See http://www.somersault1824.com/tips-for-designing-scientific-figures-for-color-blind-readers/

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- Writing: Unless you apply statistical significance tests: Replace 'significant' by 'substantial' or simply 'large', and, even better, provide concrete numbers (your results or from the literature) instead of writing 'substantial'. So, based on your own findings, the readers can judge by themselves about the magnitude of your results. The same holds for phrases such as 'relatively limited', 'important', or 'major'.
- Writing: We are generally flexible regarding which tense the text should be written in. But please be consistent, at least within each chapter (introduction, methods, results, discussion).
- Writing: Avoid subjective wording: reviewers will often object to words/phrases like "unprecedented", "paradigm shift", "amazing", "dramatic", and "remarkable". Best to present your results, and let the readers make up their minds about the magnitude of the advance.
- Writing: It's CO_2 and H_2O etc. and NEVER CO2 or H2O!

An alternative list: Nature's manuscript preparation guidelines:

When preparing a manuscript for peer review, a number of things needs to be kept in mind to make it easy for your peers to read and appreciate the work. The following list was compiled by Michael White from the Nature editorial team and modified by SP to fit the scope of IE research.

+ use double linespace, also for figure and table captions

+ use a font/font size combination that provides 12-15 words per line of text.

+ use continuous line numbers, entire manuscript must have line numbers.

+ Use a declarative title: reviewers (and editors) will often recommend a declarative title. Instead of a hypothetical title like "Trends in groundwater storage" try "A doubling of groundwater loss since 2010".

+ Avoid subjective wording: reviewers will often object to words/phrases like "unprecedented", "paradigm shift", "amazing", "dramatic", and "remarkable". Best to present your results, and let the readers make up their minds about the magnitude of the advance.

+ Avoid acronyms: a rule of thumb might be to use an acronym if the term is used at least five times. Do use common acronyms, like SST, CDW, NPP, AMOC. Avoid, if at all possible, inventing acronyms that are unique to your paper

+ Avoid words like "influence": instead, state the direction of the effect you're describing. So, instead of hypothetically writing "Precipitation influences net primary production" write "Precipitation increases net primary production". Better yet, use numbers.

+ Avoid using "significant" to mean "big" or "major": too easily confused with the results of a statistical text. Even if you are reporting the results of a statistical test, it's better to report the numerical results instead. In fact, best to avoid "significantly" entirely.

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+ Define uncertainties: probably half of initial submissions do not fully define the meaning of error bars and/or uncertainties. 95% confidence intervals, ranges, 2 sigma? Is the box plot showing the interquartile range, or something else? Tell us, in the figure legend.

+ Consider accessibility: try to use colors in a way that won't create problems for the many readers with some form of color blindness (for a good discussion and design suggestions see http://www.somersault1824.com/tips-for-designing-scientific-figures-for-color-blind-readers/)

+ Use divergent colors when appropriate: in an anomaly graph, it's often helpful to set zero as white and then ramp up to two colors

+ Simplify figures: we often see maps with colors and contours used to display the same data. This can be confusing, as the reader may think that different datasets are being displayed on the same map. Normally, one or the other is sufficient.

+ Follow a template for your abstract: The abstract/first paragraph of Nature papers is fairly standardized, and it can be helpful to follow our template, even for non-Nature papers. https://www.nature.com/documents/nature-summary-paragraph.pdf

+ Provide short titles for figure legends: sometimes this can be descriptive, like "Study area". But if possible, make the title declarative, like "Habitat fragmentation increases cloud condensation nuclei" (hypothetical!).

+ Provide inline figures and legends: at least for the purposes of initial review, it's easier and accepted/requested by most journals to provide figures and legends as part of a single PDF, with the figures placed at an appropriate location in the text.

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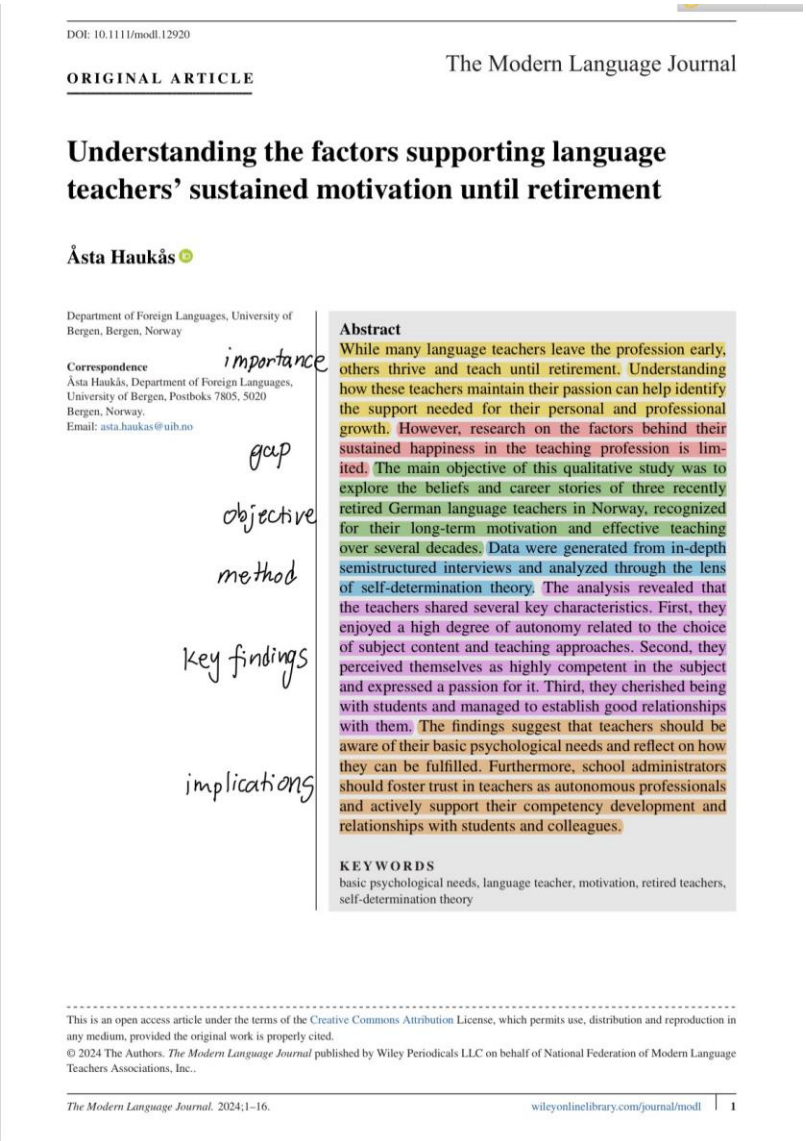
Writing a good abstract:

This Twitter screenshot below, the credit goes to @SaraJaaksola, nails down how each abstract should be structured. As IE is a method-heavy field, most abstracts should have 2-3 sentences on methods and not just one, and be a bit shorter on importance, objective, and implications.

Key advice: If your paper reports results from a quantitative analysis, its abstract must report the core quantitative findings!



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ORIGINAL ARTICLE

The Modern Language Journal

Understanding the factors supporting language teachers' sustained motivation until retirement

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importance

gap

objective

method

key findings

implications

Abstract

While many language teachers leave the profession early, others thrive and teach until retirement. Understanding how these teachers maintain their passion can help identify the support needed for their personal and professional growth. However, research on the factors behind their sustained happiness in the teaching profession is limited. The main objective of this qualitative study was to explore the beliefs and career stories of three recently retired German language teachers in Norway, recognized for their long-term motivation and effective teaching over several decades. Data were generated from in-depth semistructured interviews and analyzed through the lens of self-determination theory. The analysis revealed that the teachers shared several key characteristics. First, they enjoyed a high degree of autonomy related to the choice of subject content and teaching approaches. Second, they perceived themselves as highly competent in the subject and expressed a passion for it. Third, they cherished being with students and managed to establish good relationships with them. The findings suggest that teachers should be aware of their basic psychological needs and reflect on how they can be fulfilled. Furthermore, school administrators should foster trust in teachers as autonomous professionals and actively support their competency development and relationships with students and colleagues.

KEYWORDS
basic psychological needs, language teacher, motivation, retired teachers, self-determination theory

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Figure: Standard structure of a journal paper abstract, by @SaraJaaksola

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Citation styles and reference management:

Compared to other fields, citation rules in IE are quite relaxed. For papers, the citation style (author-year vs. numbering) is given by the journal and I know that many colleagues are flexible regarding the style to be used in master or doctoral theses. Unless your report contains only a handful of citations a reference manager is needed. Examples are given below. Zotero and Mendeley seem to be most widely use these days, but Endnote and Bibtex are also common.

+ Guide to citation styles

https://www.citethisforme.com/guides

+ Mendeley citation manager

https://www.mendeley.com/

+ Zotero citation manager

https://www.zotero.org/

+ Endnote citation manager

http://endnote.com/

+ Bibtex citation style

http://www.bibtex.org/

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3. Industrial ecology tools, research infrastructure and work procedures

Industrial ecology is a maturing field and there are more and more experience, tools, and infrastructure to build upon. As part of professionalism, both young and experienced scholars must make an effort to keep up to date with the developments of the field – it will advance their own work and increase the overall quality of the research process.

In our field, the work procedures are mostly defined within the topical sections of the field that centre around different methods or research objects, such as life cycle assessment or urban metabolism. The procedures within the different fields are comprehensive and detailed, and there is lots of teaching material and text books available. The Industrial Ecology open online course also gives an overview and features a list of other IE-related online teaching material (https://www.industrialecology.uni-freiburg.de/teaching).

Here, only a list of entry points for the different research topics is provided that every IE researcher should be aware of:

+ The ISIE homepage, with the section home pages, a job market, blog, announcements and a webinar collection: https://is4ie.org/

+ The industrial ecology open software dashboard, an inventory of available open source software on GitHub and beyond: https://github.com/IndEcol/Dashboard

+ The industrial ecology clusters on the data sharing platforms Zenodo: https://zenodo.org/communities/indecol/

and FigShare: https://figshare.com/

+ The openLCA database nexus, the source for LCA datasets: https://nexus.openlca.org/

+ The industrial ecology data commons prototype and related data model:

https://www.database.industrialecology.uni-freiburg.de/

+ Python hacks for industrial ecology: https://github.com/IndEcol/OpenScience/wiki/Python-hacks-for-industrial-ecology

Anything missing from this list? Please send an email to in4mation@indecol.uni-freiburg.de

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Acknowledgement

The author acknowledges Julian Allwood for sharing the description of the general structure of a scientific report (section 2.2), Helen Hamilton for sharing her insights on good scientific writing (section 2.3), and Michael White (Nature editorial team) for sharing his experience with manuscript formatting for peer review (section 2.3).

References

The web sites below were accessed in August 2019.

[1] Core principles of science ethics: Israel National Council for Research and Development.

http://in.bgu.ac.il/en/Global/Documents/General/ethicseng.pdf

[2] On Being a Scientist: The National Academies Press, Third Edition, 2009.

https://www.nap.edu/catalog/12192/on-being-a-scientist-a-guide-to-responsible-conduct-in

[3] Plagiarism definition from the Wikipedia: https://en.wikipedia.org/wiki/Plagiarism

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