PLACARD

Transforming knowledge management for climate action: a road map for accelerated discovery and learning

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About this paper

Developed under the European H2020 PLACARD (PLAtform for Climate Adaptation and Risk reDuction) project, this paper draws on the authors' extensive work exploring the barriers to the uptake and use of knowledge about climate change adaptation and disaster risk reduction globally. It is informed by available literature, and dialogue with EU policymakers, relevant researchers, practitioners and professionals, and outreach in workshops and panel discussions with targeted stakeholders at key international conferences held over the past five years. The paper's recommendations and insights arise from extensive experience with European and international projects focused on devising tools to better support climate-resilient decision making. The authors' related work has specifically focused on finding better, universal ways to classify, visualise, and appraise adaptation risks – and the strategies to deal with them. In this respect, the report further draws on over a decade of experience gained in developing and operating the long-lived global knowledge-sharing platform weADAPT; pioneering the PLACARD Connectivity Hub search and discovery tool; engaging early in the international Climate Knowledge Brokers network; and collaborating with experts in the development and content enhancement of the free-to-use Climate Tagger tool.

This paper aims to provide inspiration and direction for the stakeholders and actors involved in, and in a position to enable better information and knowledge management (IKM) to meet the challenge of the global climate change and sustainable development agendas. Specifically it targets: 1) donors, to contribute towards significant societal benefits made possible through better IKM and its contribution towards more informed decision-making; 2) knowledge professionals and researchers to improve practices and come together as a community to solve a global issue; and 3) data scientists to leverage emerging IKM and artificial intelligence (AI) technologies to build and analyse large datasets to support climate action.

While this paper focuses on the climate change adaptation (CCA) and disaster risk reduction (DRR) communities in Europe, the technologies and approaches it describes serve as a springboard for wider purposes. The basic tenets apply globally and to all areas of climate action. Indeed, the power of the technologies and practices described in the paper is that they connect relevant knowledge across disciplines, sectors, scales, and policy frameworks – thereby connecting knowledge associated with sustainable development, climate change mitigation, ecological conservation, and human health.

Contents

Key messages

1. To an unprecedented degree, people are generating huge amounts of data, information, and knowledge for two key, global missions: addressing climate change, and achieving the sustainable development goals. Harnessing and leveraging such information are urgent tasks. They are within our grasp. They require a new mindset, investment in key management practices, and the collective will to operate in ways that make finding and sharing information easier.

2. The status quo does not meet the world's needs. Individual operations work independently without universal standards that connect related work across the globe. Previous efforts to classify, categorise and structure climate-relevant knowledge as needed have failed to reach their full potential – or their intended audiences. As a result, people cannot easily and rapidly find the information they seek. When they do find information, they often cannot understand it – and thus cannot use it. In such an environment, people around the world cannot learn from one another's experiences, policies, and research, or from successes and failures.

3. The basic, often overlooked organisational practice of Information Knowledge Management (IKM) offers a viable way forward. Such management practices can make possible the exchange of knowledge needed to meet the scale of these challenges. IKM technologies at hand and on the horizon have the power to connect and analyse vast amounts of climate-relevant data and information in ways that previously were not possible. Leveraging these technologies can make data, information, and knowledge "FAIR" – that is, findable, accessible, interoperable, and reusable.

4. Technology offers unprecedented opportunity, but it cannot solve the problem on its own. A single organisation cannot solve the problem on its own, either. Success requires global cooperation and coordination. Progress largely hinges on the adoption and use of universal, standardised IKM practices by relevant organisations, governments, the private sector, civil society, and the research community. Some standards already exist; others must be developed.

5. The advent of the IKM technologies and the use of practices outlined in this paper can transform the Internet into a true global database that is up to the global missions at hand. The use of these tools and practices can lay the foundation for further advances from artificial intelligence (AI) approaches now on the horizon. As its use in other fields already demonstrates, AI can yield new insights and knowledge. Leveraging AI in the future requires that changes in management practices begin in the present. Absent the widespread adoption of IKM tools, practices and standards, the climate change agenda will be ill equipped to take advantage of the new analytical power of next-generation tools.

6. This paper serves as a siren call for greater leadership and funding, and for summoning the collective will to create a step change in the prevailing conduct of fundamental IKM practices. Such measures need and deserve greater attention and investment to achieve their potential to serve the global climate and sustainable development agendas.

Executive summary

To address the urgent, existential threat posed by climate change, and to achieve a just and inclusive transition to a net-zero carbon economy by 2050 (EC, 2019), will require a transformation in how the world seeks and finds the information to address these enormous, interrelated missions. Thus, a half a century after the dawn of the Information Age, the new imperative is to move forward from having information to harnessing it. We can no longer afford to squander time or resources searching for the most credible or relevant kernel of information tucked away in some virtual corner. We cannot afford to implement a measure without learning from the experiences of a similar intervention that proved its worth elsewhere. Nor can we afford to implement measures that have previously been revealed as ineffective or counterproductive. In short, we need to find better, faster ways to learn from one another, and to work together as a true global community addressing global problems.

The technological tools to achieve such ambitions exist, or are on the near horizon. Moreover, a rethink of one basic, often neglected aspect of work – knowledge management standards and practices – has the power to both open up and speed up access to knowledge throughout the globe with potentially transformative effects.

This paper presents a road map forward on these issues. It outlines how taking basic steps to change the conduct of a basic organisational practice – information and knowledge management (IKM) – can accelerate action on climate change. It outlines technological tools to achieve this. It presents ways to hasten widespread knowledge uptake and implementation. It describes how present-day technologies and emerging artificial intelligence approaches can and should be leveraged to maximise learning from existing and evolving knowledge on climate action. It provides examples to illustrate the benefits of better connecting climate (and other) knowledge. Our focus here is on actions that reduce the impacts of climate change – specifically by supporting adaptation to climate change and reduction of disaster risk. Nevertheless, the fundamental actions outlined here can also empower efforts to achieve sustainable development goals and meet international carbon emission commitments to mitigate climate change.

Let us be clear: the problem is not that we lack information. The sheer amount of information at our disposal is staggering – at many times utterly overwhelming. Insights come from all corners of the globe, from community to international levels, and from science, government, civil society, and the private sector. In theory, much of this knowledge is available online. But in practice, *relevant* knowledge is difficult or impossible to find – or to use. This failure to capitalise on the use of our collective knowledge contributes towards:

- A lack of coordination and collaboration between projects, people, agencies, organisations, and networks working on similar issues.
- Duplication of efforts, resulting in wasted resources.
- Missed opportunities for learning from the successes and failures of previous and ongoing work.

- Deepening and hardening of information silos, with connections between different strands of work becoming increasingly harder to make as more knowledge emerges from ever more research and policy niches and disciplines perceived as "unrelated".

These issues inhibit progress in best practices, and impede efforts to build upon others' work. Addressing them is essential for optimising use of the resources being dedicated to climate action, for achieving international goals, and for creating an environment that spurs innovation.

This paper argues that the keystone of the solution to these issues lies in better connecting the data, information and knowledge we have: using IKM technologies to link relevant content on climate action – be it reports, projects, organisations, people, policies – across platforms, websites and the web at large, and across the multiple scales, disciplines and sectors involved in implementation. The technology exists to make such needed connections possible. This paper describes how these technologies – taxonomies, ontologies and knowledge graphs – when widely implemented, can support a shift towards Linked Open Data: a protocol that reconfigures the World Wide Web from a fragmented collection of individual data sources into a global, interconnected database for query and analysis – a "Web of Data".

We describe a key step in this progress: the development and widespread use of harmonised, shared taxonomies. These are structured terminologies that can be used to describe both qualitative and quantitative content, such as reports, datasets, articles, organisational and experts' profiles. Shared taxonomies enable integration and linking of related knowledge among communities, supporting content discovery, collaboration, and analyses of integrated data. Such capacities yield new insights. And, they become more powerful still through the addition of 1) shared ontologies, which provide semantic information on how objects link to each other, and 2) knowledge graphs, which combine this information with data to produce large, detailed "'ecosystems" of knowledge that can be subject to complex queries.

With this paper we introduce these technologies, and we explain how their collaborative development and widespread adoption can be transformative for the climate agenda. IKM can do all manner of things: support understanding, accelerate knowledge transfer and learning, enhance collaboration, better connect relevant activities, support comparisons and connections, and link and integrate datasets to generate new knowledge. We explain how deployment of these technologies can reveal to users not just what they seek, but what they previously did not know they ought to seek. Importantly, we describe a road map that can help make this a reality.

Crucially, these technologies and enhanced IKM infrastructure set the stage for greater progress from upcoming artificial intelligence (AI) approaches. The next great advance on the information technology front, AI promises leaps in analytical capability with the potential to transform how we manage and interact with data, information, and knowledge. AI approaches enable the analysis of unprecedented amounts of information. Thus, this technology allows users to draw new and greater insights from collective knowledge on climate action. Failure to coordinate and pursue shared IKM technologies such as those outlined in this report will undermine our ability to take full advantage of AI, marking a catastrophic, missed opportunity for progressing action on climate and sustainability.

These technologies also provide infrastructure needed to deliver FAIR[1] data that support equitable access to knowledge on climate action. In its final report, the European Commission Expert Group on FAIR Data outlined two high-priority areas of activity: 1) the development, refinement and adoption of shared vocabularies, ontologies, metadata specifications and standards central to interoperability and reuse at scale; and 2) the increased provision and professionalisation of data stewardship, data repositories and data services (EC, 2018). The expert group called for "more concerted, coordinated and better resourced community efforts". In this paper we echo these calls to action, and outline ways to help realise the FAIR data goals.

This paper serves as a needed call to action. It urges the European Commission to align its own efforts with other key actors leading relevant initiatives around the globe to support knowledge specialists to redesign management practices. No individual actor can achieve the road map described in this paper – but each individual actor can and must play a part in tapping our collective wisdom. The only way we can help one another is by agreeing on a common and collaborative approach amongst all stakeholders in the European and global knowledge management enterprise.

Taking full advantage of IKM technologies for the benefit of everyone pursuing climate and sustainability action – including actors across government, business, academia, and civil society – requires not a new tool, but a new way of thinking. What we need is the wherewithal to do things differently. Those of us in these fields must embrace a step change in IKM approaches. We must work as a global community of knowledge managers, researchers, practitioners, and policymakers to address these issues of universal concern.

1 Findable, Accessible, Interoperable and Reusable to the greatest extent possible. "FAIR is a significant concept in its own right since it offers a set of principles to enhance the usefulness of data." (EC, 2018).

A road map to transform IKM for climate action

The road map consists of two parts. The first offers six concrete steps that knowledge and platform managers can take now. The second outlines sixteen steps for the medium and long terms.

How to begin: steps to take now

Platforms, portals, projects, and organisations sharing content relating to climate action *can already start preparing and contributing* towards an integrated and unified view of heterogeneous knowledge relating to climate action by:

1. Following existing good practice principles and standards where possible. Examples of such measures include "open government" principles, World Wide Web Consortium (W3C) standards, and FAIR principles (Wilkinson et al. 2016); and for taxonomies and ontologies, the Simple Knowledge Organization System (SKOS) and Web Ontology Language (OWL) standards.

2. Sharing existing taxonomies and ontologies (both formal and informal) with one another to support widespread uptake and use, and to provide an overview of the terminology being used in different focus areas and within different websites. Where possible, joint mapping exercises can be used to (a) "link" existing terms (concepts) between the taxonomies, and (b) expand metadata associated with terms (such as their synonyms).

3. Engaging experts to validate and improve taxonomies by adding missing terms, metadata, and information on how the terms in the taxonomies behave and relate to each other (their semantics) to produce ontologies. Metadata can include definitions from each community on the use of terms, as well as "scope notes" that describe context-specific use (and, importantly, excluded uses) to help non-experts understand and apply technical terms.

4. Adopting and implementing shared taxonomies and ontologies within their websites to tag content with relevant key terms. A free to use tagging tool, such as the Climate Tagger, which also enables retrospective tagging of large datasets, could support this step. Importantly, the use of synonyms for key terms allows for individualisation of terms used by different websites.

5. Developing application programming interfaces (APIs) to support interoperability and content sharing across websites. This is essential for crowd-sourcing, collating, and sharing pertinent knowledge.

6. Promoting awareness of the added value and importance of IKM within and across institutions in supporting knowledge uptake, informing decisions, and enabling powerful analysis using AI approaches. This is particularly important for those in senior leadership and those in a position to direct investments towards IKM.

How to advance: steps to take over the medium and long terms

The activities advocated here[2] involve the development of taxonomies and ontologies that follow SKOS and OWL standards. They require specialised expertise. As such, an initial step for all actors involved is to assess current capacity and literacy for this work, and to engage with IKM (specifically taxonomy and ontology) professionals to address capacity gaps. The goal is to use the shared taxonomies and ontologies for the development of a more comprehensive and sophisticated tool, a climate action knowledge graph.[3]

The collaborating groups of actors ("actor groups") must lead some of the steps by focussing on specific topics, sectors and frameworks (the "focus areas"). A wider community of actors must address other steps to contribute towards climate action. Here we highlight each step according to the participation and leadership required: whether **led by actor groups**; **addressed as a community**; or undertaken by a **combination of the two**.

Although presented here as a linear process, many of these activities can be undertaken in parallel and iteratively, enabling involvement of new actor groups at different stages. This process can emerge at different scales, for example within given subtopics of a wider agenda. Leadership and funding sufficient to direct and support collaborative action from the community are paramount. A European Union secretariat dedicated to enhancing IKM for climate change and sustainable development agendas could provide this.

1. **Collate and evaluate existing taxonomies and ontologies in relevant focus areas (topic, sector, policy framework).**

2. **Collate all the different data, knowledge and information types that the shared taxonomy and ontology need to describe and relate.**

3. **Conduct interviews and hold workshops with stakeholders to further explore the nature of content, terminologies and users' information and knowledge needs, including the design of IKM systems and knowledge integration.**

4. **Share, discuss and use outputs from steps 1-3 to explore significant overlaps in terminology and to establish components of a common ontology.**

5. **Specify a set of (prioritised) core IKM activities that taxonomies, a common ontology, and the resulting overarching knowledge graph should support.**

6. **Agree on standards for quality assurance, metadata, and governance of the taxonomies, common ontology, and knowledge graph, and make key decisions about their licensing and publishing.**

7. **Agree on standards for the implementation and use of the shared taxonomies and common ontology to connect relevant content across websites, enable accurate clustering of knowledge for different decision-making contexts and ensure the linked data content pool is of sufficient quality to be useful to users.**

2 See Chapter 4 for greater detail on the road map.

3 A knowledge graph is a model of a knowledge domain comprising concepts, classes, properties, relationships and entities covering multiple domains, various levels of granularity, and data from multiple sources.

8. Develop a governance model that specifies how future changes and enrichments of taxonomies, common ontology and resulting knowledge graph will take place.

9. Develop a common ontology framework to attribute characteristics to terms and describe the relationships between terms.

10. Develop the focus area taxonomies and ontologies based on existing taxonomies and ontologies and their overlaps, the common ontology framework, the terminology used in that area, the content types that need to be described and the needs of stakeholders.

11. Enrich and expand the taxonomies and ontologies through text analysis of documents, websites, and other content to identify new terms for integrating into the taxonomy.

12. Add metadata to the focus area taxonomies to provide a rich base of information on the terms, including definitions and how they are used in different contexts .

13. Analyse overlaps and, where appropriate, link the focus area taxonomies and ontologies to produce an integrated, shared climate action taxonomy and ontology.

14. Implement the integrated taxonomy and ontology in knowledge management systems to produce a knowledge graph of climate action.

15. Continue to enrich and expand the taxonomies, ontologies, and resulting overarching knowledge graph.

16. Regularly test and evaluate the taxonomies, ontologies, and resulting knowledge graph and explore their potential to better support users, including through AI approaches and the development of "“smart”, responsive IKM systems.

This road map provides an achievable pathway for transforming IKM to make the most of the vast array of climate-related knowledge already at hand but currently scattered across various sectors, communities of research and practice, organisations, governments, and private sectors. It enables the global climate change action community to build on, further develop and integrate existing work across these focus areas, to provide a global, integrated climate action data, information, and knowledge. These basic changes in organisational practices have transformative power. They can help people find and use needed knowledge. They can connect people and actions across the Web and across the world. They can empower policymakers, the private sector, the research community and society at large to collaborate in ways that allow marshal resources to address the defining global issues of our times.

Introduction

In Paris in 2015 leaders from around the world committed to limit global temperature rise to 2ºCelsius above pre-industrial temperatures, and to pursue efforts to limit the increase further to 1.5°Celcius (UNFCCC, 2015). A special report in 2018 by the Intergovernmental Panel on Climate Change highlighted the depth and speed of changes needed to achieve these targets (IPCC, 2018). The impacts of climate change are increasingly evident throughout the world, and public outcry and demand for "climate action" have grown, but policies have yet to implement measures at the scale needed.

The global missions of the Paris Agreement, the 2030 Agenda for Sustainable Development, and the Sendai Framework on Disaster Risk Reduction strongly interlink. They recognise that actions related to climate change, associated climate risks, sustainable development, and disaster risk planning have synergies and trade-offs. As such, the pursuit of any one of these processes in isolation, without due regard to the potential ramifications on other agendas, risks failing to achieve desired outcomes, and the possibility of further exacerbating other problems. To achieve these interconnected goals, we need to optimise how we learn from and collaborate with each other.

Around the world, actors across the research, practice, and policy spectrums are scrambling to address these complex issues (Box 1). No matter their circumstances, they ask the same fundamental questions: What is the best action to take? Where can I find information? Who has expertise? What works? What are the costs?

Actors want easy and fast access to data required for sound decision-making. They need to stay abreast of emerging issues, activities, and technologies as things change. They want to learn from the experiences of others, who may be working on the same issue far away. They need to learn about and compare solutions that worked, and to understand the key components of success. Conversely, they want to know how and why "solutions" failed.

Many of the answers to these questions are out there, somewhere, but they are difficult and time consuming to find. Huge amounts of data, information, and knowledge overwhelm users. Information lies strewn across multiple websites and platforms, often specific to particular communities of research and practice. The fragmented knowledge landscape is hard to navigate. People cannot find the information they seek quickly or easily; they miss out on opportunities to learn from related areas of work and practice; and they do not easily see the links between the international agendas.

The situation underscores the inherent contradiction of the Information Age. We are simultaneously overwhelmed by too much information and underinformed because of a lack of relevant information.

This dilemma need not be the rule. A basic organisational management practice – information and knowledge management (IKM) – has the power to change things. Such practical operational measures and the related technological tools that enable them hold unique potential to spur faster, more efficient learning and collaboration on the climate and sustainability agendas across the globe.

Box 1: The unmet needs of users

During a workshop for the PLAtform for Climate Adaptation And Risk reduction (PLACARD) in Brussels in 2017 national-level decision-makers from European governments, and representatives from NGOs shared the challenges they face daily when seeking information on climate change adaptation and disaster risk reduction. These issues are:

Discovering content – Participants struggle to quickly find relevant information, particularly given time constraints. When they find relevant information, they struggle to sort and filter material according to a target interest, such as a specific climate risk. They also struggle to find more detailed information on specific activities; for example, they can locate EU project descriptions, but not project activities or outputs. The content they uncover lacks evidence (such as evaluations of certain technologies) and examples (such as case studies). **The upshot: People do not find information about practices or approaches to emulate – or avoid**.

Understanding content – Participants struggle to find information that they can understand and interpret. The quality of data is not clear. The terminology used is often incomprehensible, relying too heavily on jargon and technical terms. **The upshot: People who find information struggle to understand it well enough to use it**.

Finding people, particularly peers – Participants struggle to find who is doing what, both where and how. Even when they find an overview of certain activities with a specific location and focus, they seldom find the names of people undertaking these activities, or ways to connect with them. As a result, participants are often unaware of relevant activities being undertaken in their region and/or in contexts relevant to their work. Participants want to connect with peers facing similar challenges to discuss relevant experiences and insights, but they often cannot locate them. **The upshot: People working in related fields do not make potentially valuable connections to help one another**.

In a nutshell, IKM is the practice of making content of all kinds readily findable and usable. "Content" refers to almost anything anyone could want: data, projects, reports, activities, legislation, news, details about organisations and businesses, and ways to reach the people who make them work. IKM employs a systematic approach to sharing content to ensure those searching can find relevant content. In the context of the World Wide Web, which has led to an explosion of available information of varying quality, good IKM enables actors to find relevant content quickly and easily.

Two characteristics – speed and ease – are crucial. Human and financial resources are limited, and information that cannot be found quickly is often not found. The prevailing impediment is not that the information is lacking. The missing element is speedy, easy access.

Rethinking IKM practices and using the technologies presented in this paper have the potential to give the climate and sustainability agendas newfound traction. These tools can connect disciplines that might seem disconnected. Better IKM infrastructure can provide the machinery needed to help users understand and engage with content no matter their background or discipline. That is, it can make content not just findable but also comprehensible to experts and non-experts alike, and to all manner of potential users, such as policymakers, business owners, and students.

This paper argues that IKM is the most promising springboard for global coordination and information sharing at our disposal. Better IKM opens the door to coordinating relevant actions and processes, steering resources to greater effect, and connecting actors around the globe. IKM is essential for harnessing and leveraging vast knowledge that has been – and continues to be – generated. It offers a way to integrate and analyse information, and to yield new insights to advance understanding. A unified vision for IKM procedures could be transformative, setting the stage for:

- Finding information faster.
- Gaining greater access to climate-related data and activities.
- Integrating data and datasets to yield new knowledge and innovation.
- Creating greater transparency on what information is used, and how (and importantly, what information is not used).
- Increasing collaboration and communication.
- Allowing people to more easily learn from successes and failures, so that they do not reinvent the wheel or repeat mistakes.

By transforming the way we approach IKM we can achieve FAIR data: data that are "Findable, Accessible, Interoperable and Reusable to the greatest extent possible…(to) give data greater value and enhance their propensity for reuse, by humans and at scale by machines" (European Commission expert group on FAIR data, 2018, p. 10).

The final report of the European Commission Expert Group on FAIR Data outlines two high priority areas of activity for achieving FAIR data that explicitly leverage IKM technologies: 1) the development, refinement and adoption of shared vocabularies, ontologies, metadata specifications and standards that are central to interoperability and reuse at scale; and 2) the increased provision and professionalisation of data stewardship, data repositories and data services (EC, 2018). The group called for "more concerted, coordinated and better resourced community efforts". The IKM technologies and road map outlined in this paper can help make FAIR data a reality. The road map provides a basis for data stewardship, data services and interdisciplinary interoperability that are "essential to the realisation of FAIR" (ibid., p. 11).

The widespread adoption of these IKM technologies and practices is also a requirement to taking full advantage of technologies on the horizon: artificial intelligence (AI) applications. Such next-generation tools promise to analyse unprecedented amounts of information, and to draw new and greater insights from collective knowledge on climate action. Machine-learning techniques have already demonstrated an ability to measure alignment of publications with the SDG goals (LaFleur, 2019).

AI has power to conduct analysis more quickly (in minutes rather than months) and more accurately (with lower error rates than with human brain power alone). Such analyses can yield new knowledge. Indeed, AI is already demonstrating its analytical power in responding to another global crisis: the COVID-19 pandemic. AI tools developed by data scientists and pharmacologists at BenevolentAI identified a drug that is now the subject of further research for its potential to reduce the impact of the virus, and prevent the viral infection.[4] By scouring scientific literature related to the virus, AI tools helped rapidly pinpoint a promising treatment that "surprised both the company that makes the drug and many doctors who had spent years exploring its effect on other viruses".

If the climate change and sustainability agendas want to take similar advantage of AI, prevailing practices must change. The relevant players must deliberately coordinate to pursue fundamental information management procedures and tools outlined in this report.

We are not starting with a blank slate. Some IKM technologies – such as the use of keyword-tagging to connect content – are already used in the climate change adaptation (CCA) and disaster risk reduction (DRR) communities, but are limited to individual platforms and websites, with each taking its own approach. Free-to-use tools are available, but they are poorly tailored to describing CCA and DRR content. Terminologies and taxonomies are and continue to be developed (including by the European Commission and High-Level Expert Group on Sustainable Finance, the Agricultural Information Management Standards Portal (AIMS) of the Food and Agricultural Organization of the United Nations (FAO), the United Nations Environment Program's (UNEP) Sustainable Development Goals Project (SDGIO) and the UNISDR Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction). The next urgent mission is working together to harmonise and link these efforts. We must produce and use shared taxonomies that allow us to connect relevant knowledge, and to make it understandable.

Against this background, "Transforming knowledge management for climate action: a road map for accelerated discovery and learning" was developed under the European H2020 PLACARD (PLAtform for Climate Adaptation and Risk reDuction) project, to kick-start a culture shift in IKM approaches used by the CCA and DRR communities, which share many common objectives but operate largely independently of one another. Though the paper focuses specifically on these two targeted climate change agendas, the technologies and approaches described here apply globally and to all areas of climate action.

This paper draws on the authors' extensive work exploring the barriers to the uptake and use of knowledge about CCA and DRR globally. It is informed by available literature, and dialogue with EU policymakers, researchers, practitioners and IKM professionals, and outreach in workshops and panel discussions with targeted stakeholders at key international conferences held over the past five years. The paper's recommendations and insights arise from extensive experience with European and international projects focused on devising tools to better support climate-resilient decision making.

4 Cade Metz (30 April 2020) How A.I. steered doctors toward a possible Coronavirus treatment. New York Times.

The authors' related work has specifically focused on finding better, universal ways to classify, visualise, and appraise adaptation risks – and the strategies to deal with them. In this respect, the report further draws on over a decade of experience gained in developing and operating the long-lived global knowledge-sharing platform weADAPT; pioneering the PLACARD Connectivity Hub search and discovery tool; engaging early in the international Climate Knowledge Brokers network; and collaborating with IKM and taxonomy experts in the development and content enhancement of the open-source Climate Tagger tool.

The approach and technologies in this paper outline steps that must be taken to leverage AI methodologies that promise to further maximise the learning potential of collective knowledge. This vision is in line with the European Commission's recognition of the enormous value of digital tools (EC 2020a, EC 2020b).

This report presents a road map for a common and collaborative approach to accelerate progress on climate and sustainability agendas. Measures described in these pages require collective efforts from all relevant initiatives. No single entity can do this unilaterally. Each actor must play a part so that all can tap collective wisdom. This paper serves as a call to action to all leading relevant initiatives to join such efforts – and for the leadership and funding needed to spur action.

Chapter 1 explores current challenges in IKM, why users' needs remain unmet, and describes the ideal knowledge management landscape for users. Chapter 2 describes technological tools that knowledge managers and knowledge producers in individual organisations and on independent platforms can implement now. It details how these tools can help address current shortcomings to better serve areas of research, policy, and practice. Chapter 3 outlines how certain new technologies can enhance the discoverability, accessibility, and connectivity of content. It shows how these technologies can support automated and standardised approaches, and how more powerful analysis of content can yield new insights. Chapter 4 provides a road map to guide the way forward. It lists specific actions that can be taken now, and in the medium and long terms. In sum, this paper serves as a siren call urging all involved to take the steps that can open up and speed up information exchange, leverage new technologies, and give the climate change and sustainability agendas needed momentum to advance their missions.

Chapter 1: Current challenges and users' needs

To figure out what needs to be done we first need to understand the issues at hand: what attempts have been made to make climate action knowledge more accessible, what barriers have these efforts faced, what are the obstacles to knowledge uptake by decision makers, and what are their information and knowledge needs.

This chapter explores current challenges in IKM, why users' needs remain unmet and what an ideal knowledge management landscape could look like from a user perspective.

1.1 Current challenges in climate-focused IKM and decision-making support

Climate change adaptation and disaster risk reduction – two fields of research and practice that both aim to reduce climate risk – have long sought ways to better organise their respective knowledge. However, improving collaboration, communication and coordination between these communities, requires better integration of this knowledge. To support knowledge uptake, efforts have long attempted to classify, categorise, and structure knowledge on risks, options, strategies and assessments in different ways through online repositories and databases. Examples range from the ADAM digital adaptation compendium[5] (Hinkel et al. 2009), more than a decade ago, right through to more recent initiatives such as Climate-ADAPT's adaptation options database, PreventionWeb's Themes and Hazards databases, and PANORAMA's solutions for a healthy planet. Surprisingly though, little has changed in terms of enhanced "search and discovery" of knowledge in the CCA and DRR fields over this time. In the meantime, the onslaught of knowledge generation continues, with multiple emerging subfields within CCA and DRR potentially siloing in different directions e.g. community-based, ecosystem-based, urban adaptation. Each requires specialist curation, due to differences in objectives, concepts and terminology used. But, rather than creating many fragmented communities of knowledge, connection and linkages between this data are vital – new approaches to knowledge management are more important than ever.

5 European Commission 6th Framework Programme project.

Box 2: Knowledge-sharing challenges: the case of the World Bank

A World Bank study (Doemeland and Trevino, 2014) illustrates knowledge-sharing challenges. The report found:

- More than 31% of the World Bank's own policy reports are never downloaded.
- Almost 87% of its own policy reports are never cited.
- Only 13% of its publications have been downloaded 250 times or more.
- Its multi-sector reports received more frequent citations.

A lack of knowledge flow within the organisation exacerbated the situation. Downloads and citation consistently increased when the World Bank Research Department provided support designed to facilitate internal knowledge-sharing across different departments within the organisation.[6] This is an example of overcoming the disconnect between research silos – which surface not just among organisations, but also within them.

Knowledge-sharing reforms at the Bank were intended to position it as a "catalyst for global knowledge by connecting practitioners and by supporting networks of researchers, policy makers, and civic organisations keen to learn about what works and how to implement successful results" (World Bank Quarterly Business and Risk Review, 2013). This was used "to diffuse innovation at scale, so that successful projects and programs are replicated under the right conditions or with the right adjustments by practitioners across the world" (ibid.). Increasing the discoverability of knowledge products (through, for example, standardised taxonomies and metadata, which are designed to increase the likelihood of more downloads and citations) reinforces internal knowledge-sharing mechanisms and reduces dependency on them alone. To address this the Bank established the Open Knowledge Repository (OKR), which significantly boosted discoverability and dissemination of all Bank reports. By complying with Dublin Core Metadata Initiative (DCMI) standards, the OKR supports optimal discoverability and reusability of the content, and interoperability with other repositories.

To advance towards our Agenda 2030 Goals, more guided journeys through knowledge have been developed, such as the guidance from the UNEP Global Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA), to support national adaptation planning processes (Hinkel et al. 2013). More recently, a multitude of 'smart' apps have emerged to support climate-resilient decision-making, ranging from those for day-to-day climate action (e.g. reducing carbon footprints), planning (e.g. seasonal forecasts), through to early warning systems (e.g. for flood risk) and capacity building (e.g. providing good practice advice and peer-to-peer learning from patterns identified in large crowdsourced datasets).

6 Cross support is defined as the staff time of an expert purchased from outside the responsible unit for specific tasks (Doemeland and Trevino, 2014).

Box 3: The need for shared and unified taxonomies – the case of "green" finance

There are many reasons that IKM is more important than ever to meeting the Agenda 2030 goals and achieving climate-resilient development. For example, under the European Green Deal "green" financial instruments are likely to play a key role in mobilising financial resources. However, a lack of clear legal definition of "green" has led to disputes and allegations of "green washing" of projects that are not as environmentally beneficial as promised. This highlights the need for clear guidance for defining and identifying green projects and assets. A unified taxonomy for "green" climate-related projects has been shown to increase effectiveness of the investment decision process and to reduce the transaction costs associated with collecting and processing non-financial information (Leitner et al. 2020). However, uptake of standardised processes to support decision-making remains slow.

To manage climate and environmental risks requires better integration of these risks in the financial system. In the EU and indeed, across the world, investors, insurers, businesses, governments, and citizens need data to develop instruments that make climate change a fixture of their risk management practices. Yet because few formal, open, or shared taxonomies exist to classify such data in the climate change field, there is low likelihood that organisations will invest in the initial cost of engaging with this approach. Due to the investment and cultural shift required to transform existing approaches, key organisations both across the EU and at the international level need to take the lead and coordinate such action.

A start in the right direction is the development of an EU Green Taxonomy (TEG, 2019) by the European Commission and High-Level Expert Group on Sustainable Finance, for the identification of green projects and green financial instruments. This also incorporates climate change adaptation and disaster risk reduction indicators and metrics. The aims are to avoid inaccurate "green" labels, and to ensure that climate change adaptation and disaster risk reduction are better reflected in decision-making processes and related financial flows (Leitner et al. 2020).

There are also powerful visualisations that simplify complex data (e.g. identifying supply chain risks and opportunities for sustainable production, or interconnections between knowledge within and between online knowledge platforms (Bharwani et at., 2015). These are all promising steps, signalling recognition of the need for better standardisation to enable more effective discoverability, decision-making, transparency, learning and improved content comparability. However, few of these approaches have reached their full potential – or their intended audiences (see Box 2).

Impeding the advance of such IKM-oriented activities are:

- **Voluminous data** – It is difficult to explore, organise and analyse such vast amounts of data, particularly if it is unstructured or does not follow a common format or standard.
- **Fragmentation of information** – Knowledge is scattered across multiple platforms, data portals, and websites, though objectives may be similar.

- **Disparate terminologies** – Communities each have their own terminologies. These terminologies are often discordant in that they often use different terms to mean the same or similar things, resulting in inconsistency in the way related content is described or understood (see Box 3).

These challenges partly reflect the lack of agreed upon or widely adopted IKM standards for climate action. General standards for IKM are available. For example, the International Organization for Standardization (ISO 30401:2018) lays out requirements for effective knowledge management. The World Wide Web Consortium (W3C)[7] standards ensure that industries adhere to a specific way of publishing their data.

This lack of climate action standards arises from the scale of the task of bringing disparate communities and their knowledge together, and in some cases a low awareness of the extent to which existing, accessible IKM technologies can significantly transform this picture.

1.2 What is needed from the users' perspective?

A PLACARD workshop undertaken with national-level EU stakeholders and NGO representatives ("users" of knowledge) in 2017 highlighted significant and persistent IKM issues that lead to missed opportunities for collaboration and knowledge-sharing (Box 1). Participants then outlined what characteristics, components and functionality online knowledge repositories could provide to address these issues (Figure 2).

The results of these discussions highlight the need for **enhanced searchability**, in particular the need to **link related content** such as project descriptions, outputs and implementing teams, and to **filter and cluster search results** according to certain attributes. Stakeholders want **fewer entry points** and **interoperability** between regional, national and international platforms so that they can find content from among platforms rather than searching each site individually.

Stakeholders want greater **accessibility** with respect to terminology and format; they want presentation of materials that allow for the **quick appraisal** of key content (for example methods used, lessons learned, barriers encountered). Stakeholders want **dynamic, responsive systems** that help them find relevant knowledge, for example through automated alerts of new, relevant content, user help desks, and expert request services (automated or not). They want interface designs that provide **tailored entry-points** that reflect their needs and level of knowledge.

Other, similar workshops reach the same conclusions. For example, a workshop held with national stakeholders in Dublin in October 2019 raised analogous requests (O'Dwyer et al. 2019).

While many of these needs have long been recognised they have so far proved challenging to address. The technologies and collaborative approaches proposed here make it possible to ramp up ambition and start to effectively address these barriers.

7 The World Wide Web Consortium (W3C) is an international community that develops open standards to ensure the long-term growth of the Web.

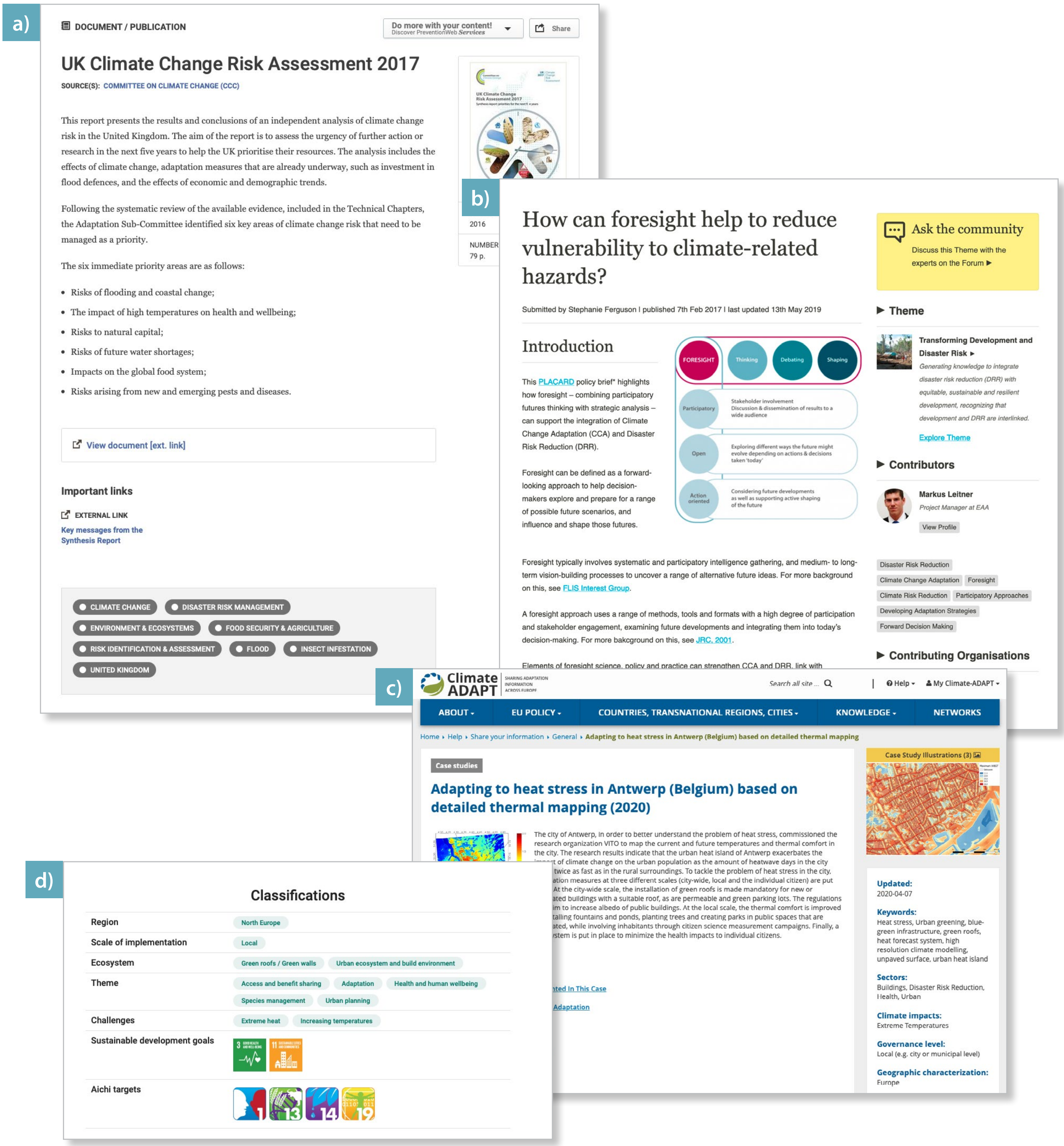


Figure 1: Linking content and empowering searches through keyword-tagging

This figure shows how keyword-tagging of resources is currently used on knowledge-sharing platforms. (a) PreventionWeb uses controlled tagging of resources to link relevant content; these tags, included as dark-grey buttons at the end of articles, are dynamic and can be selected to cluster all the resources that have applied the tag. (b) weADAPT also uses dynamic tagging, included as light-grey buttons beneath the content contributor's name, to link relevant resources. (c) The European platform Climate-ADAPT uses detailed static tags, included in the right-hand column of content pages, covering multiple fields of information. (d) The PANORAMA Solutions platform uses static tags upfront on content pages to transparently classify resources according to several fields, and to indicate their relevance to international agendas. This use of keyword-tagging by these different platforms is based on separate, platform-specific taxonomies.

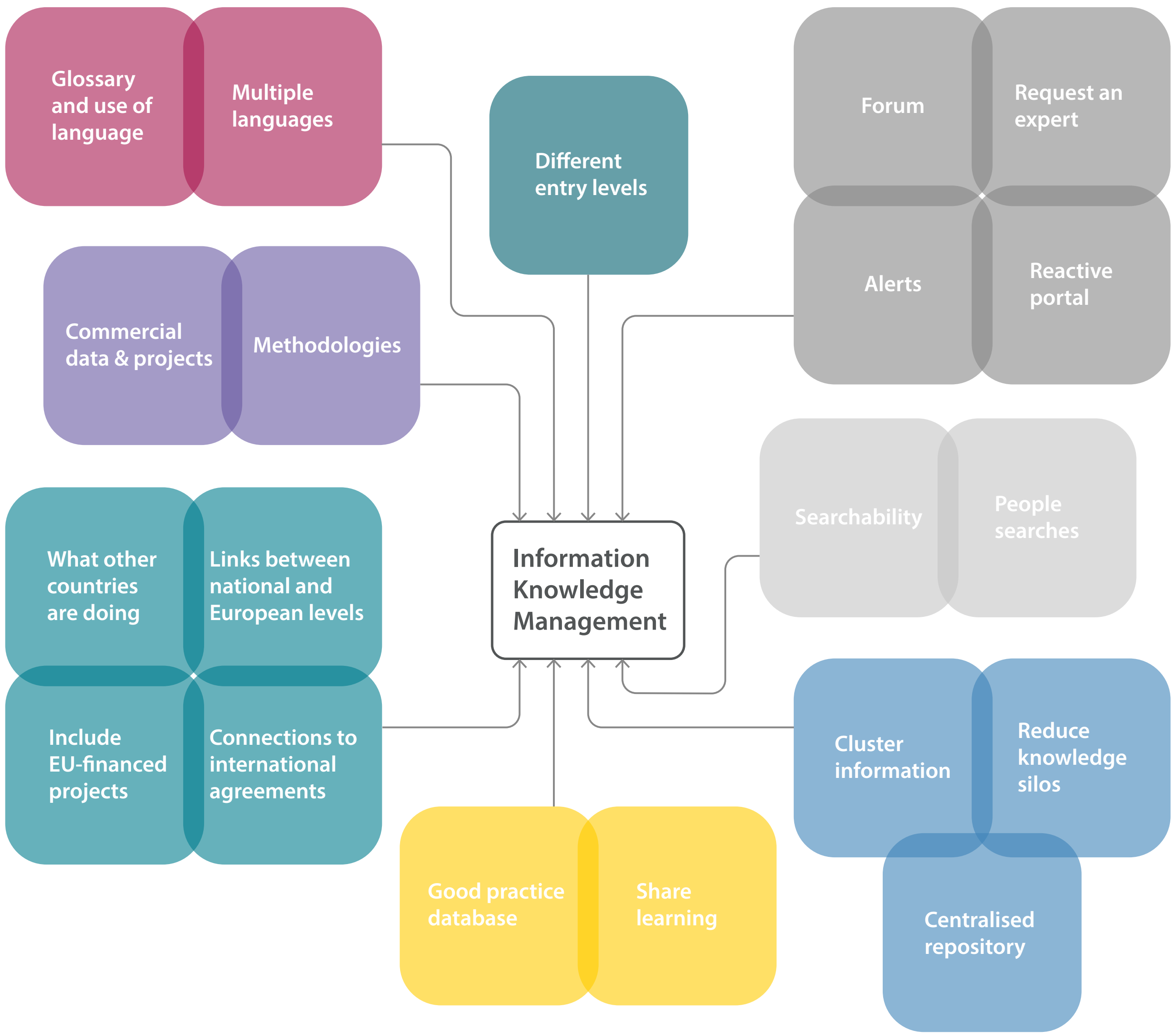


Figure 2: Components of an idealised online resource

This figure presents components of an idealised online resource for climate change adaptation and disaster risk reduction in Europe, as identified by national policymakers and representatives from non-government organisations at the PLACARD workshop "Joining forces" in Brussels, 2017. The blue circles signify idealised needs from an online resource; pink are provisions linked to language and terminology; turquoise are capabilities enhanced by the resource; grey are the functionality offered by the resource; yellow are outcomes of the resource; purple are content shared via the resource; and, dark teal are how the online resource should relate to other activities. The lines between circles show how these components should connect with one another with ballpoints indicating the direction in which this could happen, for example "Methodologies" should be incorporated into a "Good practice database", and the addition of "Methodologies" should incur an "Alert".

Chapter 2: Towards a connected web of knowledge

We have IKM technologies at our disposal to address these challenges. These technologies – taxonomies and ontologies – can be used now. Taxonomies are already used in many knowledge platforms and websites to organise and connect digital content. The issue here is that each platform and website uses their own taxonomy. While this enables improved content management and discovery, it only does so within that individual platform or website.

This chapter outlines how IKM technologies can be used to address current shortcomings to better serve areas of research, policy, and practice. It summarises the opportunities offered by the widespread adoption of a shared taxonomy for linking relevant content across the divisions of individual platforms and websites, to make it more discoverable and to help break down silos. It describes how metadata provided through taxonomies, including definitions, related subjects, and background information, can be used to make terminology more comprehensible and promote communication and understanding, particularly amongst non-experts. And it details the added value of ontologies for connecting content in more meaningful ways.

2.1 Linking data through shared taxonomies

In IKM taxonomies are collections of terms that describe a specific area. They can be used "in the narrow sense, to mean a hierarchical classification or categorisation system, and in the broad sense, in reference to any means of organising concepts of knowledge" (Hedden, 2016). In this paper we interpret taxonomies as controlled and structured collections of terms (also referred to as concepts) that encompass all the key terminology used in a subject area, and where the structure of the taxonomy (for example a hierarchy) indicates how the terms in that terminology relate to one another (Figure 3).

Taxonomies play a key role in describing and defining different areas of knowledge. Many knowledge platforms and knowledge-sharing websites already use a taxonomy to classify and organise their data into different sections by theme or topic to help users find information. In some cases these taxonomies are used to power keyword-tagging – the application of relevant descriptive terms to content – to improve searchability, and to link related content. This can also help users cluster and filter data according to multiple attributes (Figure 4).

A key challenge for most – IKM professionals and users alike – is that each platform and website uses its own taxonomy. The keywords used, their interpretations, and the general approach to keyword-tagging are not consistent across sites.

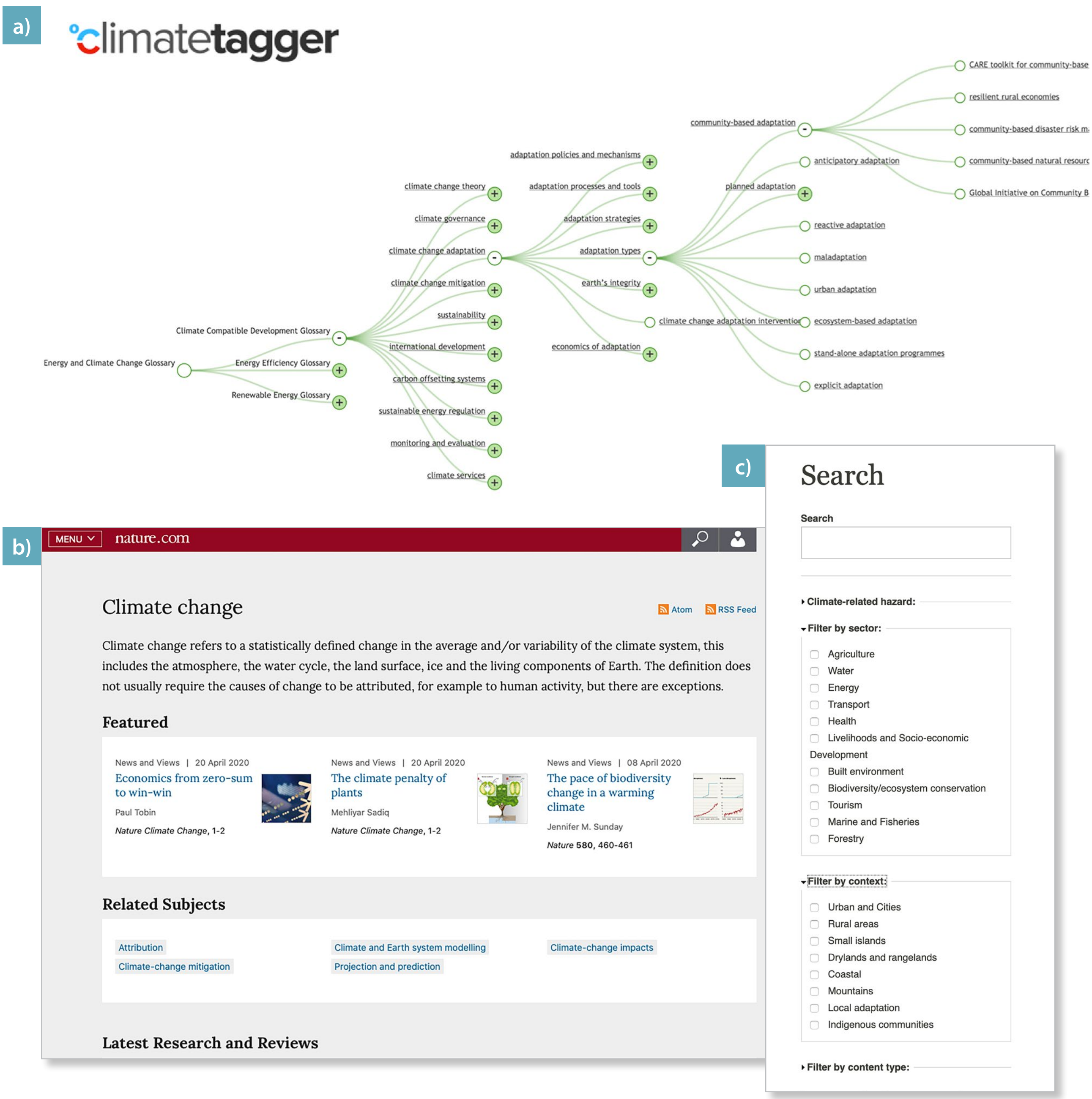


Figure 3: Taxonomies

This figure provides a visual example of a taxonomy and shows how they are used in websites. Taxonomies are collections of terms used to describe a subject area. Websites can use taxonomies to describe content, enabling easy discovery, relevant linking, and needed filtering and clustering. In Figure 3, (a) shows the Climate Tagger taxonomy (with only some branches expanded) in which the relationships between terms are described by a hierarchical structure of broader and narrower terms. (b) shows taxonomy in action on Nature.com, where the taxonomy is working in the background to link the term "climate change" with its definition and relevant content; related terms are also returned, enabling users to explore linked subjects that they may not have considered before, providing opportunity for learning (see Box 4 on metadata). (c) shows the faceted search system on weADAPT; this is based on keyword-tagging of content and enables users to drill down and cluster knowledge based on several attributes.

Developing and adopting a shared taxonomy – one that is built collaboratively and used across all platforms and websites sharing knowledge on climate action – and standards for the utilisation of this taxonomy for tagging online content would enable the linking of relevant content from across multiple platforms, portals and websites. Crucially this would enable:

- **Improved discovery and visibility of content and host platforms and websites**. The application of a shared taxonomy for tagging content on platforms and websites enables content from across different online spaces to be linked to one-another, allowing users to quickly access all the diverse content out there relating to specific topics, including reports, projects, organisations and people. This is the basis for Linked Data (see section 2.4), and enables access to this extensive and diverse data through a single entry point, reducing user effort and driving users to host platforms and websites that they may not previously have been aware of. The application of specific keyword tags improves search relevance, precluding the issue of searches returning high volumes of irrelevant data, as is the case when using search engines.

  Specifically relating content in this way enhances the visibility and discoverability of content from less-known platforms, portals, and websites, and those with poor search-engine optimisation. This supports the uptake of content from new and as-yet-unknown projects and smaller organisations that lack capacity to invest in digital communications. By using metadata (Box 3), links can also be made between content tagged in different languages.

- **Filtering and clustering of content** based on multiple keyword tags. Using tags to describe the attributes of content enables users to find the specific knowledge that meets their needs. Consistent tagging using a shared taxonomy also supports the development of dynamic decision-support and guidance tools that can use tagging to create structured pathways through knowledge resources, such as the Tandem online guidance for the co-design of climate services.
- **Improved interoperability** between platforms, portals, and websites by using keyword tags to filter shared data. Website application programming interfaces (APIs) are already used to share and receive data between websites. However, such interoperability and direct sharing vastly improve when all relevant platforms, portals and websites use the same set of keyword tags (a shared taxonomy), and apply them in a consistent way. Better facilitating such knowledge-sharing allows knowledge platforms to collaborate to better support their users and the wider community – for example, by dynamically curating and pooling knowledge on adaptation solutions. It is also an overlooked and important step in reducing content duplication across platforms and websites – which, in turn, reduces data storage requirements and their impact on energy use and climate change. See Nature.com.

These capabilities go a long way to addressing user needs: **enhanced searchability**, **linked related content** such as project descriptions, outputs and implementing teams, the ability to **filter and cluster search results** according to certain attributes, **fewer entry points** and **interoperability** between regional, national and international platforms to enable faster easier, searches.

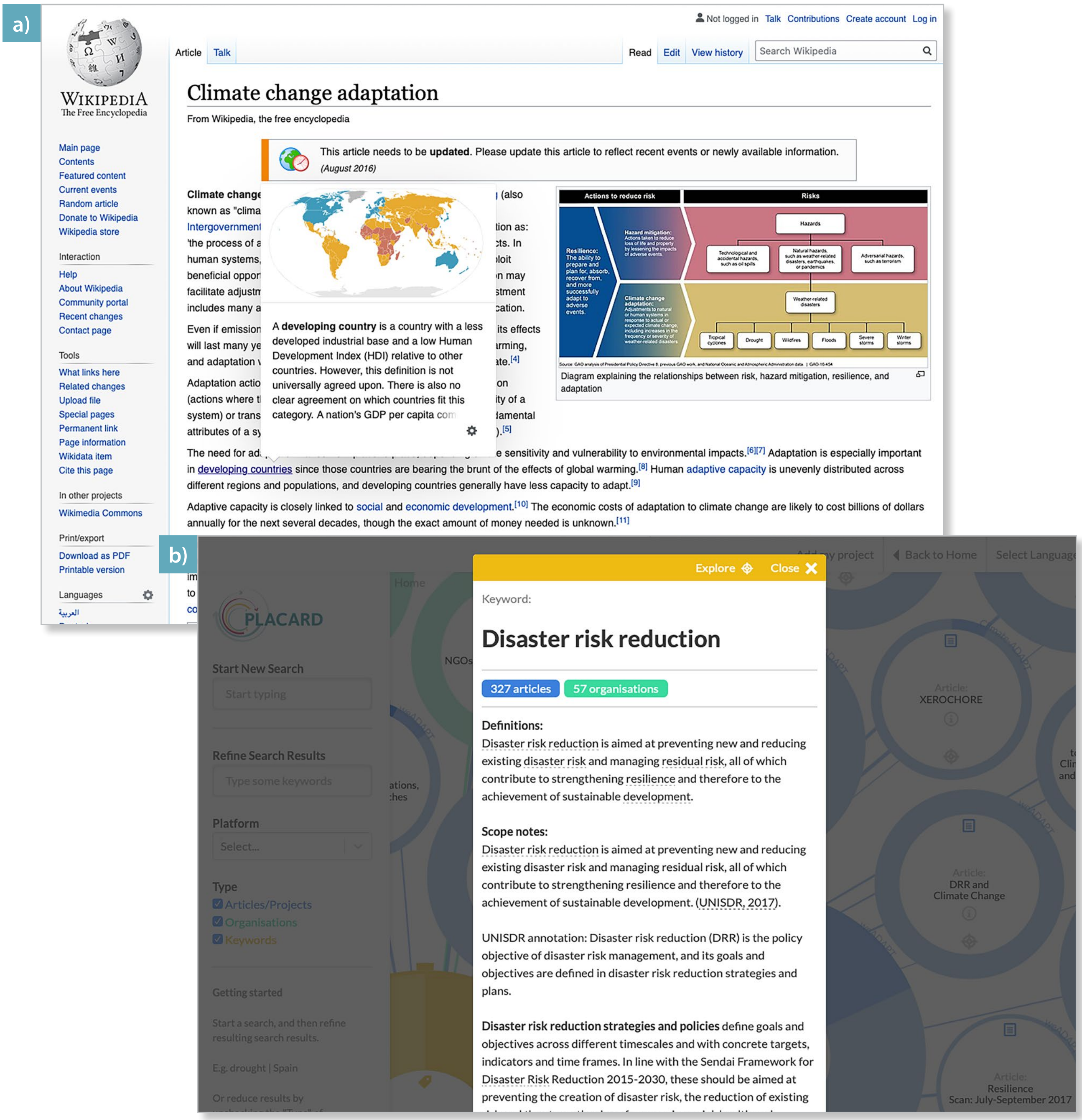


Figure 4: Using taxonomies to raise awareness of terminology

This figure shows how metadata (see Box 4) added to taxonomies can be used in websites and platforms to support understanding of language and terminology. This is crucial for supporting non-expert users, particularly where there are significant disparities between the interpretations of terms by different communities. (a) In Wikipedia taxonomy metadata are used to help users understand and explore different terms; the system provides a description of the term in question when the user hovers her cursor over the word. (b) In the PLACARD Connectivity Hub metadata are used to provide definitions for terms, synonyms and "scope notes" describing how they are used and applied in different contexts, and related terms that might be useful for the user to explore; similarly to Wikipedia, the taxonomy is also used to highlight terms in the text that users can click on for more explanation.

2.1.1 Promoting communication and understanding with metadata

Taxonomies do not just provide a means of linking data. They can also be used to actively promote learning, particularly **awareness of terminology**. Taxonomies can include an array of **metadata** associated with each keyword, for example definitions, related terms, synonyms (including the translation for other languages), documents and images. When implementing a taxonomy within a platform or portal these metadata can connect users with further knowledge relating to a given term to aid their understanding and awareness (Figure 4). Metadata can also be used to highlight related topics that users may not previously have been aware of. This is essential for improving the accessibility of technical content for non-experts – a key user need (see section 1.2). This is particularly important in situations in which non-experts encounter similar content from different fields (such as CCA and DRR) that use the same terms to describe different things. Metadata such as definitions and scope notes in particular can demonstrate how terms are defined by the different fields and sectors, and explain the reasons for these differences. While such metadata can be developed for disparate taxonomies used in individual platforms and websites, developing and using a shared taxonomy have several benefits. Users gain exposure to coherent terminology. This reduces confusion, enhances understanding, and reduces ambiguity.

While metadata can be used to promote understanding of the disparate ways terminology is used (Box 4), the development of shared taxonomy and associated metadata also presents an opportunity for coming together to clarify thinking on specific terms. The power of shared terminology for supporting shared understanding, and in turn decision-making, communication and research progress is underscored by the contemporary debate over how to define one word: green (Box 3). The debate over how to define this single word – as a description of projects and financial instruments, and whether the designation reveals certain environmental bona fides, or has been used to supply a veneer for less desirable practices – illustrates the sorts of issues that can quickly surface. This underlines the importance of the work on climate-related taxonomies, such as the EU Green Taxonomy by the European Commission and High-Level Expert Group on Sustainable Finance. These can ensure that "green" projects and financial instruments truly meet some accepted definition of green, and that related processes and financial flows better incorporate climate change adaptation and disaster risk reduction (Leitner et al. 2020).

2.1.2 Providing for website/platform individuality

Importantly, the implementation of a shared taxonomy need not preclude the individualisation of terminology used on different platforms and portals, and by different communities. The metadata associated with terms in a taxonomy provide significant scope for including synonyms and related terms (Box 4). These can be used to link and integrate related content even when a certain research community or organisation has a preference for using certain synonyms.

Metadata used in this way harmonises terminologies and connects related content across "siloed" sectors and areas of research and practice.

Box 4: Using taxonomy metadata to harmonise terminology, enable integration and raise awareness

One barrier to the use of a shared taxonomy is that different communities and user groups habitually use different terms to describe the same or similar things. For example, "adaptation options", and "adaptation measures" are both used to describe activities that can be used to promote adaptation to climate change. Similarly, the terms "ecosystem-based approaches" and "ecosystem-based adaptation" are very closely connected, but not identical.

Taxonomies enable the use of different terms for the same purpose (**synonyms**) and for closely related terms to be described (**related terms**). Content with keyword tags means that a search for a given term will find "hits" that use any of its synonyms. This allows for linking, even in the face of individualisation within participation platforms/portals, and different languages used. Critically, it also enables the integration of these data. Identifying and connecting synonyms link content despite these variations.

Content tagged with related terms can be programmed to appear in searches as secondary or similar results, or as suggested alternative searches. This is a powerful way of connecting the user with additional relevant knowledge that they may not have previously considered.

This is of course different to situations in which the same term is used to describe different things. This is a key issue for communication between the fields of DRR and CCA, for example. Consider the term "protection" for instance. In DRR's common parlance, the word refers to civil protection measures and mechanisms. In CCA, by contrast, the term usually refers to laws and policies on species and ecosystem protection, or to longer-term risk reduction, such as flood and coastal protection. Whilst such differences are valid, identifying them and clarifying the related impacts on decision-making processes are essential for supporting greater mutual understanding.

It is possible to add "scope notes" to term metadata that describe how the term can, is and should be used, and to provide details about different usages.

This is the thinking behind the development of the PLACARD taxonomies for CCA and DRR. These taxonomies aim to raise awareness of how these two communities use terms, and to lay the groundwork for improved IKM (Barrott & Bharwani, 2018). Another example is UNEP's effort to develop a Sustainable Development Goals Interface Ontology (SDGIO) to formalise the structure of connections between goals, targets, and indicators related to the SDGs (Zaino, 2016). The objective of the SDGIO is not to change the way member states conceptualise their own understandings of terms, but to create a shared understanding and a way to represent the diversity of definitions used in reference to the SDGs. This aims to make the diversity of usage more transparent to people looking for data relevant to SDG indicators, and to help them discover content, even if they use a different description or term.

2.1.3 Existing tools and a proof of concept

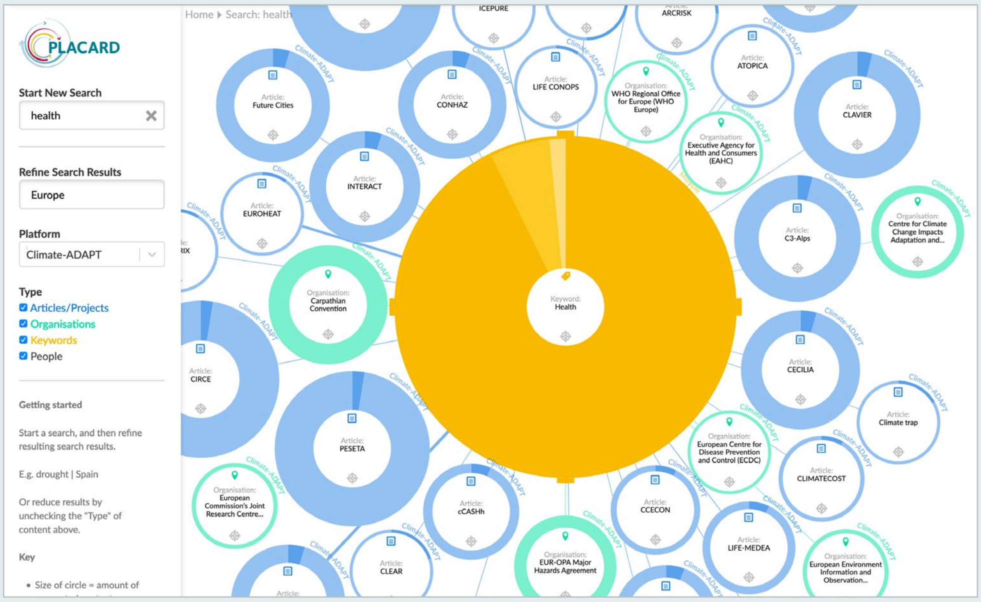
The tools to use shared taxonomies to apply keyword tags and thus describe content across disparate platforms and websites are already available. Implementation can begin without overwriting existing knowledge structures tailored to specific audiences of platforms and websites. Several platforms and portals use existing taxonomy-based tagging tools such as the Climate Tagger (Box 5) alongside other taxonomies. For example, weADAPT uses the Climate Tagger alongside OpenCalais and user-contributed terms. Such tools enable a "content pool" to link content from disparate websites. This is a step towards "Linked Data" – structured data which is interlinked with other data so it becomes more useful through semantic queries (Bauer and Kaltenböck, 2016). Such tagging tools can use text analysis and machine-learning approaches to suggest keyword tags for content, and to automatically tag content, enabling the tagging of large datasets retrospectively. This has the power to both reduce the burden on knowledge managers, and to provide for a level of standardisation in the way tags are applied.

Box 5: Demonstration case: the Climate Tagger

The Climate Tagger is a web-based, free-to-use keyword-tagging tool based on a taxonomy of approximately 5,000 concepts in the field of climate change development, renewable energy and energy efficiency. Available in five languages, the Climate Tagger harmonises tagging and retrieves information from many climate change fields. Through its "Content Pool", Climate Tagger allows a single entry point for organisations to easily connect their data and information resources with other Climate Tagger users and across multiple platforms. Use of its metadata (taxonomy terms) makes such connections possible. The Climate Tagger makes a user's content on one platform available to a larger audience of users on other platforms. Users are then more likely to discover new and unknown connections between knowledge resources. Websites such as SCOPUS and the Web of Science use this principle to link the content of multiple academic journals. Tagging can extend the same discovery power to grey literature. This is especially important for areas of research and practice such as climate change adaptation and disaster risk reduction, where insights from the ground are often captured in case studies and project reporting, as opposed to journal articles. Importantly, the Climate Tagger can also suggest tags based on text analysis, supporting standardised keyword-tagging. If many knowledge managers undertake this approach, this standardised tagging will increase the consistency of new connections across multiple sources. With further refinement, the Climate Tagger can retrospectively tag large datasets, and exponentially increase the extent of connected data in many languages.

The **PLACARD Connectivity Hub** is a proof of concept for how keyword-tagging and taxonomy can link content across multiple platforms, providing a single entry point for users to quickly search multiple platforms (Box 6). A tool for knowledge discovery, the Connectivity Hub drives users towards the participating platforms, increasing their audiences. It also utilises taxonomy metadata to harmonise keyword-tagging across these multiple platforms, and support increased understanding of how terminology is used across the fields of CCA and DRR (Box 3; Figure 4).

Box 6: Demonstration case – the PLACARD Connectivity Hub



The PLACARD Connectivity Hub is a cutting-edge, search and discovery tool that brings together resources (articles, topics, organisations) relevant to CCA and DRR professionals in a fast and efficient way. The Connectivity Hub dynamically links major European and international knowledge management platforms (e.g. Climate-ADAPT, weADAPT, PreventionWeb, Eldis) by leveraging their tagging systems. In doing so, the Hub can bring content to the user that they may not have known was relevant to their search e.g. if they are new to a topic area. In this way, the Hub is designed to accelerate learning. 'Search and discovery' will be further enhanced by the PLACARD CCA and DRR taxonomy. Furthermore, the Connectivity Hub can be a test bed for the use of artificial intelligence (AI) and machine learning if the taxonomy is enhanced with relational and/or semantic data. Resulting new and unexpected combinations of information can produce powerful, policy-relevant insights e.g. supporting learning from relevant successful climate actions elsewhere that are otherwise difficult to find.

2.2 Adding value with ontologies

Taxonomies useful for bringing order: to find things and help classify them (Blumauer and Nagy, 2020). Ontologies encode an additional layer of information about the attributes, behavior of and relationships between the terms – their semantic connections. They can be used to attribute particular characteristics to a term, classify it as a particular type of entity, and describe how it relates to other terms (Wilcke et al. 2017). For example, using an ontology, the phrase "community-based adaptation" can be categorised as an approach for adapting to climate change, assigned the attributes *takes place at the community level*, and given the relationship *promotes* sustainable livelihoods. Ontologies also facilitate the discovery of new relationships. For example, "if, within the ontology, "vegan diet" is defined as a subclass of "vegetarian diet", and "Rainbow Spring Rolls" are classified as "vegan", then these are automatically also allowed as "vegetarian diet."" (Blumauer and Nagy, 2020, p.104).

This increased expressiveness allows for additional classifications, defining multiple relationships among terms, and prescribing more specific attributes (ibid.). It is a powerful method for deriving tacit and implicit knowledge regarding how terms are used and applied, and make this explicit for non-experts and machines alike (Chergui et al. 2018).

In this way ontologies add a level of power on top of taxonomies and provide the additional contextual knowledge that lays the way for machines to think more like us. This makes the development of a shared taxonomy and ontology fundamental for leveraging artificial intelligence for climate action (see Chapter 3).

2.3 Developing shared IKM "infrastructure"

The journey towards Linked Data starts with the development of a shared taxonomy and ontology. This is no small undertaking. Developing a single taxonomy broadly involves "gathering information on what could be included and then further evaluating these concepts[8] to decide what should be included", with information largely sourced from relevant documents, subject-matter experts, taxonomy owners and users (Hedden, 2016). Machine-learning techniques can be used to help build and extend taxonomies through identifying potential terms for inclusion, for example based on the analysis of a corpus (Motta et al. 2000; Witschel, 2005). The development of an ontology requires working with subject matter experts to elicit often subtle and implicit knowledge on how terms relate to one another, their characteristics and what attributes should be applied to them (Chergui et al. 2018).

A shared taxonomy and ontology should incorporate and build on existing relevant work and so requires a review of existing domain taxonomies, ontologies and terminology (e.g. Brochhausen et al. 2011, Baur et al. 2016). Specifying the scope and purpose of a taxonomy and ontology early on is key for ensuring it is fit for purpose, particularly as terms can be arranged in different formations (Hedden, 2016).

Standards for both the development and implementation of a shared taxonomy and ontology, and protocols for their enrichment and evolution also need to be agreed upon to ensure they are used optimally and remain fit for purpose (see section 1.1). These should follow Semantic Web standards for taxonomies and ontologies, the Simple Knowledge Organization System (SKOS) and Web Ontology Language (OWL), for which there are multiple software tools available.

This calls for a deeply collaborative approach between subject matter experts, knowledge managers and IKM professionals to ensure the resulting shared taxonomy and ontology are fit for purpose. Produce a high quality, legitimate and useful shared taxonomy and ontology hinges on the participation of subject matter experts and knowledge managers who can provide the domain knowledge needed.

8 In this paper we use 'terms' in place of 'concepts'.

Box 7: Examples of shared IKM infrastructure projects

The IKM challenges faced by the climate change adaptation, disaster risk reduction and other communities working to address climate change are shared by other sectors. Many are already taking action to develop the IKM infrastructure needed to address issues presented by the proliferation and use of different taxonomies, varied implementation of taxonomy, disparite terminology and general lack of standardisation (see section 1.1).

A prime example of leadership in creating a shared, open vocabulary is the Agricultural Information Management Standards (AIMS) portal operated by the Food and Agriculture Organization (FAO) of the United Nations. Its AGROVOC controlled vocabulary – covering food, nutrition, agriculture, fisheries, forestry, and environment – is available as a Linked Open Data (LOD) set (Caracciolo et al. 2012) aligned (linked) with 18 other multilingual knowledge organisation systems. At the same time, it remains a highly specialised portal, with 80% of AGROVOC's some 37,000 concepts and +750,000 terms (available in up to 37 languages) referring to animals and plants.

In the health sector the Advancing Clinico-genomic Trials on Cancer – Open Grid Services for Improving Medical Knowledge Discovery (ACGT) Master Ontology was developed to drive "semantic grid services infrastructure" to support "discovery-driven scientific workflows in the context of multi-centric, post-genomic clinical trials" (Brochhausen et al. 2011). The master ontology (the ACGT-MO) is used to power the ACGT Platform to "(a) facilitate seamless and secure access to heterogeneous, distributed multilevel databases; (b) provide a range of semantically rich re-usable, open tools for the analysis of such integrated, multilevel clinico-genomic data; (c) achieve these results in the context of discovery-driven (eScience) workflows and dynamic VOs; and (d) fulfill these objectives while complying with existing ethical and legal regulations" (ibid., p. 9). The system includes an "application updating and evolving the ontology efficiently in response to end-user needs".

Lessons can be learned from the development of other integrated and shared taxonomies and ontologies, and related infrastructure (Box 7). For example, in developing the Advancing Clinico-genomic Trials on Cancer – Open Grid Services for Improving Medical Knowledge Discovery (ACGT) master ontology Brochhausen et al (2011) reviewed "best practices, design principles and evaluation methods for ontology design, maintenance, implementation, and versioning, as well as for use on the part of domain experts and clinicians".

Baur et al (2016) describe a successfully combined bottom-up and top-down collaborative process for integrating three taxonomies used to describe climate change information using a "tightly coupled approach" that resolves heterogeneities between the taxonomies to achieve "a common view" (Firat, 2003), while also enriching the taxonomies by adding missing terms.

These are just two examples. While there are challenges, the work of Brochhausen et al (2011), Baur et al (2016) and numerous others on taxonomy integration demonstrates that the development of a shared taxonomy and ontology can be done successfully, and at scale. They are just two examples of the documented experiences from which communities working on climate action can learn.

2.4 Achieving Linked, Open and FAIR Data

"With linked data, when you have some of it, you can find other, related, data"
Tim Berners-Lee, inventor of the Internet, on Linked Data (2006)

Implementing a shared taxonomy and ontology across multiple platforms comprises a step towards Linked Open Data, an environment of structured and interlinked information that enables powerful searches, such as semantic queries,[9] conducted by people and humans (Box 7). Such an environment makes it possible to draw upon and analyse the connections between content (Bauer and Kaltenböck, 2016). This is the basis of a "Web of Data" (a.k.a. the Semantic Web), wherein all the content across the Web is described and connected to produce a global database.

Crucially, achieving Linked Data requires data, information and knowledge purveyors to follow specific standards, including the use of Uniform Resource Identifiers (URIs) and the Resource Description Framework (RDF) for representing information in the Web. A core component of Linked Open Data are open data principles that promote accessibility – a key user need (see section 1.2) (Bauer and Kaltenböck, 2016). These include the open government data principles designed to "empower the public's use of public data held by governments", the five-star deployment scheme for Linked Open Data proposed by Web-inventor Tim Berners-Lee, and the open data policy of the European Commission.

These open data principles align with the FAIR data (findability, accessibility, interoperability, and reusability) principles (Wilkinson et al. 2016). They also support Rec. 4[10] of the Expert Group on FAIR to better enable cross-disciplinary usage of data (Expert Group on FAIR, 2018).

The World Wide Web is an unmatched and, so far, underleveraged resource for capacity development and integrating and analysing data to yield new and additional insights (Bauer and Kaltenbock, 2016). In the context of knowledge on climate action, combining Linked Data approaches and open data principles – in effect, pursuing Linked Open Data – would maximise the discoverability of content across the Web and go a long way to supporting equitable access[11] (ibid.). Crucially, it could facilitate the use of machine-supported tools that analyse, integrate and package knowledge to support climate action. This is a profound leap forward: related content scattered across multiple platforms and websites not only becomes quicker and easier to discover, it can be combined to produce large datasets for integration and analysis, and for training machines for artificial intelligence approaches (see Chapter 3).

9 "Semantic queries enable the retrieval of both explicitly and implicitly derived information based on syntactic, semantic and structural information contained in data. They are designed to deliver precise results (possibly the distinctive selection of one single piece of information) or to answer more fuzzy and wide open questions through pattern matching and digital reasoning."

10 "Develop interoperability frameworks for FAIR sharing within disciplines and for interdisciplinary research."

11 Accessibility is not just the ability to find and obtain data, information and knowledge, but the ability to understand and use it (Dilling and Lemos, 2011).

Chapter 3: Taking IKM to the next level with knowledge graphs and AI

IKM is about more than just connecting data, information and knowledge – "content" – to make it more discoverable. The IKM technologies described above have huge potential to transform how we manage, interact with and use data, information and knowledge.

This chapter outlines how IKM technologies can enhance the discoverability, accessibility, and connectivity of content, and how these technologies can support automated and standardised approaches, and more powerful analysis of content to yield new insights. It describes the advances offered by knowledge graphs – connected ecosystems of knowledge powered by taxonomies and ontologies. Knowledge graphs are the new standard in IKM. They further facilitate powerful semantic searches and provide a robust foundation for AI approaches that can generate new insights from vast datasets and power the dynamic, responsive, and interoperable systems users want. Shared taxonomy and ontology are the keystone to realising this potential.

3.1 Taking IKM to the next level with knowledge graphs

The use of Linked Open Data standards, taxonomies and ontologies help to connect, classify, and analyse data, and make it accessible. As described in Chapter 2, taxonomies describe the terminology used in a knowledge domain, while ontologies add an additional layer of semantic information, describing the attributes, behavior of and relationships between terms. Together, taxonomies and ontologies provide a detailed model of all the content in a subject area – this is the foundation of a knowledge graph (Figure 5): "ontology is the blueprint for all information within a domain, while taxonomy converts the information contained in ontology into a format used to generate actionable data and information." (Blumauer and Nagy, 2020).

Knowledge graphs can be "envisaged as a network of all kind[s of] things which are relevant to a specific domain or to an organisation" (Blumauer, 2014), describing both the objects of interest – their character and attributes – and the relations between them (Figure 6) (Noy et al. 2019).

They act as a "fabric" that connects across data silos (Blumauer and Nagy, 2020). Importantly, they can comprise numerous taxonomies, ontologies, and other knowledge organisation systems, and so can connect multiple disparate sources of data. As a result, knowledge graphs can make complex queries across all kinds of content and heterogeneous data sources, thus breaking up existing data silos and connecting content in "smarter", more meaningful ways (SWC, 2016, Blumauer and Nagy, 2020).

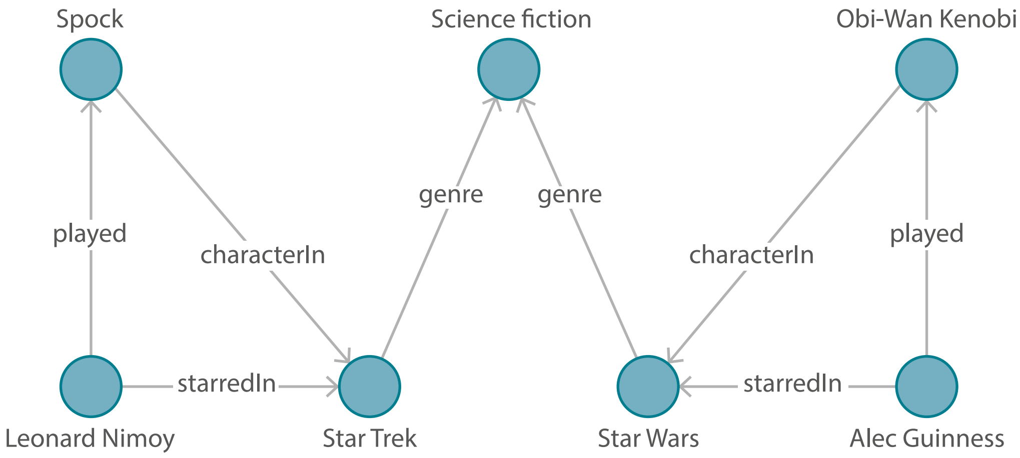


Figure 5: An example knowledge graph

This figure provides an example of a basic knowledge graph. Taxonomies describe a knowledge domain in fixed tables of columns and rows (often visualised as branches; see Figure 3). Ontologies provide information on the relationships between and characteristics and attributes of the terms in the taxonomy. Knowledge graphs use taxonomies and ontologies to model a domain of knowledge. After Nickel et al. (2015).

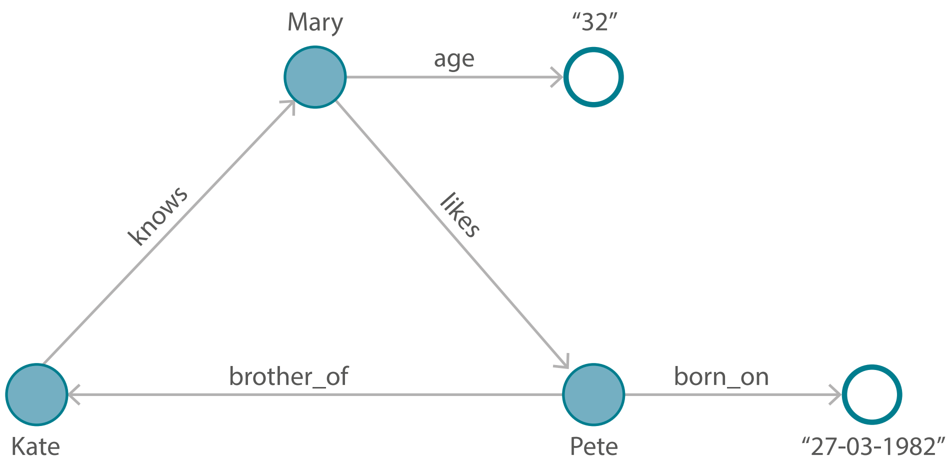


Figure 6: A sample knowledge graph displaying attributes

This figure provides another example of a basic knowledge graph, this time showing how attributes are included. This is a graphical representation of the statements: "Kate knows Mary. Mary likes Pete. Mary is aged 32. Pete is the brother of Kate. Pete was born on 27th March 1982". Edges (lines with arrows) represent binary relations. Vertices' shapes reflect their roles: solid circles represent entities, empty circles represent their attributes. After Wilcke et al. (2017).

Many people already use graph technology without even realising it, for example when they use Amazon's Alexa, Google Assistant, and Google to answer questions (Box 8). These day-to-day searches, and the resulting recommendations, rely on knowledge graphs.

You can see the Google knowledge graph in action when you use the Google search engine; results do not only return relevant content, but are able to identify, classify and bring together multiple different types of relevant content as well as suggesting additional related content (Figure 7). This reflects a significant advantage of knowledge graphs: they can store and connect lots of different types of content.

Box 8: Examples of knowledge graphs

The use of knowledge graphs is far from limited to Google's search engine. For example:[12]

- Facebook also relies on knowledge graphs to keep track of networks of people, and the connections between them. The knowledge graphs also track other data points (such as geographic locations, events attended, and favourite artists and movies) that allow Facebook to build a "picture" of its users. The relationships between data points are as valuable as the data points themselves when it comes to building social networks.
- Netflix uses knowledge-graph technology to organise information from its vast catalogue of content, drawing connections between movies, TV shows, actors, directors, and producers. The technology helps them predict what customers might like to watch next, promoting the "binge-watching" model of consumption.

Actors everywhere currently use Google and other search engines such as Ecosia and Bing. However, these currently have limited coverage and ability to link climate-action relevant concepts and their complex relationships at the level of detail required to fully leverage the extensive and growing knowledge available (Figure 8).

This is why climate action domain experts, knowledge managers and shared community taxonomies and ontologies are essential. Machines cannot understand the broader context; someone or something needs to feed them this knowledge. Taxonomies and ontologies provide the framework through which machines can analyse content. The insights and added value of knowledge graphs are only as good as the level of development of the underlying taxonomies and ontologies (Rohrseitz, 2019). The development of effective knowledge graphs also requires a significant amount of relevant data – far more than most organisations and even some knowledge platforms have (SWC, 2016).

The development and adoption of a shared taxonomy and ontology for climate action, combined with Linked Open Data best practices would provide the datasets needed to develop and expand a **climate action knowledge graph**. This would revolutionise the way people share and consume knowledge, and would set a stage for leveraging artificial intelligence (AI) approaches that take a more holistic view of climate action knowledge.

12 From: Knowledge graphs and machine learning – the future of AI analytics? and Noy et al. (2019).

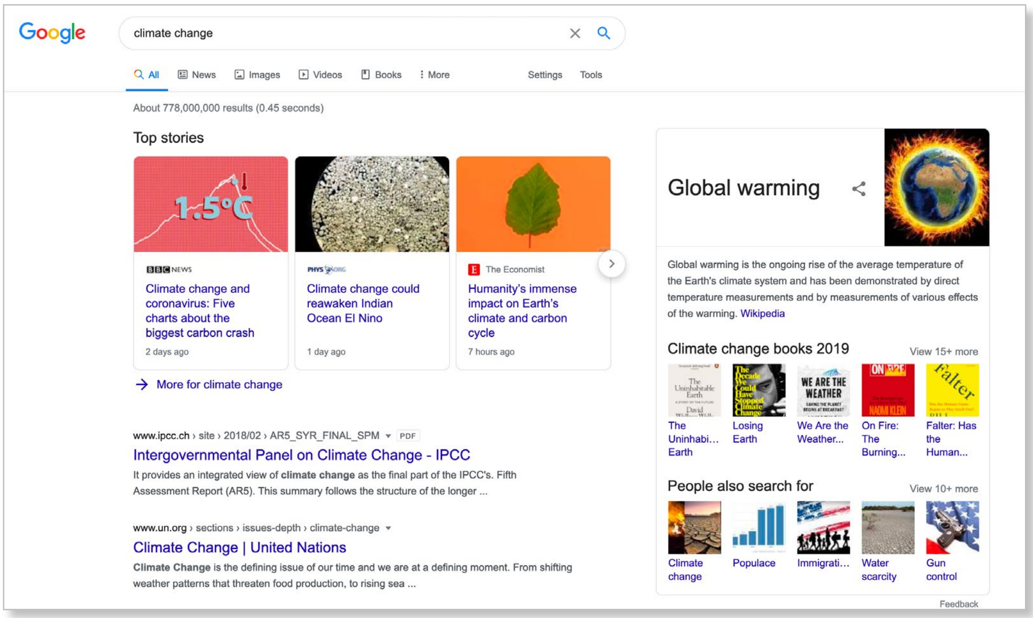


Figure 7: The Google Knowledge Graph in action

This figure demonstrates how Google searches, powered by Google's Knowledge Graph, are able to connect diverse content from across numerous websites ('databases'). The knowledge graph classifies this content, for example as news items, to enable users to selectively engage with different content types. It is also able to recommend other relevant content based on the knowledge model and on user analytics, which are used to refine and expand the knowledge graph.

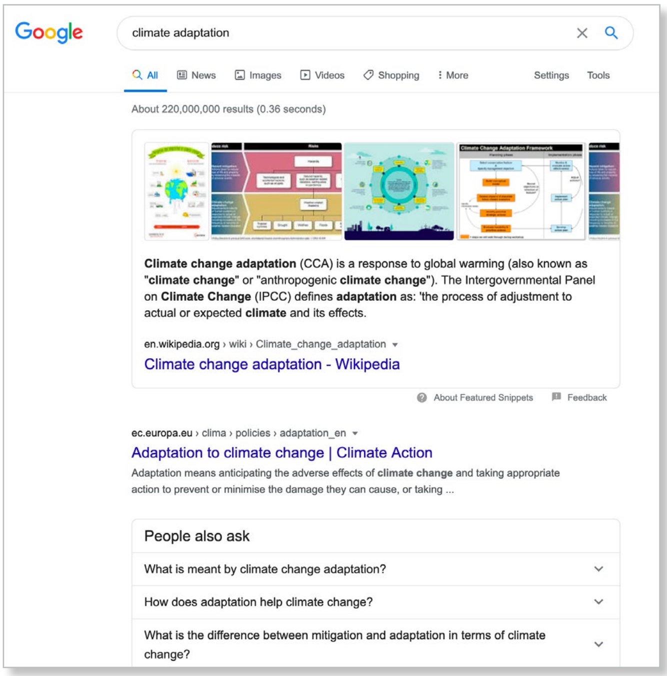


Figure 8: Google search results for "climate adaptation"

This figure shows how Google searches return useful links to background information and common questions asked (powered by analytics) and other relevant content, but do not currently suggest related material. Websites' search engine optimisation heavily influences results,[13] meaning it likely misses information from less optimised sources.

13 Google Search Engine Optimization (SEO) Starter Guide.

3.1.1 Knowledge Graphs and artificial intelligence as self optimising technologies

Artificial intelligence (AI) approaches can be used to organically extend and evolve a knowledge graph. Google, for example, continuously extends its knowledge graph by using a mix of several techniques, based on machine learning and manual curation, and supported by analytics data from users' interactions with the knowledge graphs (Noy et al. 2019). Machine learning can help to extend knowledge graphs (through, for example, "corpus-based ontology learning"), and in return, knowledge graphs can help to improve machine-learning algorithms (through, for example, "distant supervision") (Blumauer and Nagy, 2020).

This integrated approach ultimately leads to systems that, after an initial setup phase, work like self-optimising machines that can automatically evolve to incorporate new content, terms and relationships (SWC, 2016). Although human supervision is necessary to ensure the quality of new connections, the resource needs are lower compared to manually updating a taxonomy and ontology. This presents a potentially more sustainable way forward for connecting climate action knowledge compared to relying on human development of taxonomy and ontology alone.

3.2 Going beyond discoverability with AI

The practices outlined in Chapter 2 do more than make content easier to discover. When applied in a systematic way they also make it possible to analyse, integrate and combine content in more meaningful ways. This brings forth the potential to yield new insights, generate more holistic knowledge, enhance collaboration, support widespread learning and better equip us to deliver on our international goals. For example such practices have the ability to:

- **Visualise, analyse, and track the emergence of new methods, approaches, technologies, and policies relevant to climate action**. Example: enable the identification, tracking and comparison of the number and location of projects and policies focusing on specific climate risks or using particular approaches. This can support dynamic visualisations of the climate action landscape that can yield new insights, including on who is doing what and where, who is collaborating, and what solutions are being used and where (Bharwani et al. 2015). Such an approach could be used to identify and track adaptation activities underway in different countries and regions, and thereby support the Global Stocktake on Adaptation (UNFCCC, 2015).
- **Combine, integrate and analyse datasets to elicit and communicate new insights and relationships**.[14] Example: the integration and analysis of knowledge on ecosystem-based approaches, and ecosystem health across the fields of CCA, DRR, and ecosystem conservation (content tagged with relevant keywords such as nature-based solutions, Eco-DRR, ecosystem-based adaptation, ecosystem services, nature conservation, biodiversity protection) to build a more comprehensive database of solutions and indicators and encourage collaboration across these siloed areas of research and practice.
- **Automate the classification analysis and systematic comparison of documents to gain new insights using fewer human and financial resources**. Example: the analysis and comparison of diverse governmental documents to assess alignment and investigate gaps, such as has been done for the SDGs (described below) (LaFleur, 2019).

14 A simple example of this in the healthcare sector is provided here (vocabulary can be taken to mean taxonomy).

- **Identify patterns in knowledge-sharing and learning**. Example: tracking of the emergence and development of a focus topic such as forced migration, or identifying common themes across multiple goals and targets to investigate synergies and trade-offs.

Many of these capabilities are already possible with the systematic use of taxonomy, ontology, text analysis, data mining and artificial intelligence approaches such as machine learning (e.g. LaFleur, 2019; Sobral et al. 2020). The semantic information brought by ontology increases this analytical capacity further. Finally, knowledge graphs transform these capabilities through creating large, high-quality datasets for analysis (Blumauer and Nagy, 2020).

3.2.1 Powering Artificial Intelligence approaches

Artificial intelligence (AI) is a rapidly evolving field comprising various subsets of work, including machine learning, deep learning and natural language processing. In the EU, AI has become "an area of strategic importance and a key driver of economic development" that "can bring solutions to many societal challenges".

A linchpin in AI is that, much in the same way as people use their education and experience to analyse information, machines require a framework to help them make sense of data. Through providing structured data on key terms, and their attributes, behavior and relationships between them, **taxonomies and ontologies provide the knowledge models that help machines to learn** (Blumauer and Nagy, 2020).

> *"Without some sort of useful map or scheme, Artificial Intelligence becomes noise, mere echoes between wires. Taxonomies and ontologies provide machines powerful tools to make sense of data."* *Adrian Bowles, Founder of Storm Insights.*

The upshot of knowledge graphs is that they enable machines to think more like us. We effortlessly connect objects and understand their context and how they relate to each other based on our experience. For machines to be able to see the world as we do, and thereby interact with and analyse it, these connections need to be made explicit; they need to be told or learn (through machine learning) about these objects and how they connect (Blumauer and Nagy, 2020). Knowledge graphs provide the holistic, sophisticated view of their knowledge domains that enables machines to make connections that are intuitive to us.

Knowledge graphs also store data in a graphical format. This means that both *data points* and *relations* can be analysed quickly and at scale. This enables powerful queries at significantly reduced computing power compared to data stored in other formats. This in turn empowers machines to deal with large arrays of complex, interrelated data, and sets the stage for artificial intelligence-based applications (Blumauer and Nagy, 2020).

This is a critical leap since artificial-intelligence (AI) approaches can and are helping to facilitate and automate data analyses with increasing levels of sophistication and at a fraction of the time and cost compared to human-led activities (EC, 2020b). AI technologies such as machine learning, deep learning, natural language processing and image classification can be significantly enhanced when they are combined with knowledge graphs, which provide machines with base knowledge on the area of interest (e.g. Marino et al. 2017, Logan et al. 2019).

Crucially, the use of knowledge graphs in AI can support "explainability"[15] and make the decisions made by AI more transparent (Blumauer and Nagy, 2020). This is essential for supporting excellence and trust in AI, a lack of which could undermine uptake of these technologies (EC, 2020b). To realise the potential of AI collaborative efforts are needed to develop a shared knowledge graph for climate action, and the shared taxonomy and ontology that underpin it.

> *"In order to discover relevant data, perform machine-analysis at scale or employ techniques such as artificial intelligence to identify patterns and correlations not visible to human eyes alone, we need well-described, accessible data that conforms to community standards."*
> *Turning FAIR into reality: Final Report and Action Plan from the European Commission Expert Group on FAIR Data*

An example of how **machine learning** can support content analysis in the climate and development sector is the "proof of concept" demonstrated by the UN Department of Economic and Social Affairs (LaFleur, 2019) that measured the degree to which the many resolutions, speeches and reports produced by the UN each year align with the Sustainable Development Goals (SDGs). Text analysis techniques were combined with machine learning to build a classifier that could determine the similarity of the content of different publications to each of the SDG goals.

An initial step was the building of topic models – weighted collections of terms that uniquely describe each topic – based on selected publications that reflected each of the 17 SDGs. The analysis using the classifier produced an "SDG score" – a potential way to measure the level to which international policy commitments are being met by different activities.

Clearly, this approach could be useful for many areas of climate change research, both in identifying strengths, but more importantly in verifying gaps and areas in need of further attention. It illustrates how taxonomies and machine learning could be used to identify patterns and areas of convergence or disparity and gaps in different contexts and geographies. This is a potentially powerful toolbox since such policies and programmes often lack measurable targets or clearly defined expected outcomes that can be easily compared and tracked (ETC/CCA Technical Paper 2018/3; OECD, 2017). Additionally, the learning that results from such a process would also inform and refine climate-related taxonomies with the emerging new terms and actions being used by actors and institutions nationally.

3.3 How Knowledge Graphs could transform IKM for climate action

Leveraging the potential of knowledge graphs to empower AI approaches opens the door to AI-powered applications that could transform IKM approaches. While these applications typically still require a degree of expert human supervision to ensure their quality, they enable advanced data science approaches that can revolutionise the ability to gather, analyse and learn from the array of knowledge produced (Noy et al. 2019).

15 "Explainability means that there are other trustworthy agents in the system who can understand and explain decisions made by the AI agent." (Blumauer and Nagy, 2020, p.44).

Importantly, knowledge graphs cultivate Linked Open Data and can thus provide the extensive datasets needed to train machines. Armed with this, technology teams can then start to explore all the ways these can be applied to promote climate action and resilience. There is huge, and in the case of climate action, largely untapped, talent and potential to develop applications to address diverse issues. **What they lack is domain knowledge**. The CCA and DRR communities of research and practice can contribute to filling this need (see Chapter 4).

The examples provided in section 3.2 described the enhanced analytical capabilities brought by the IKM technologies described in this paper. The following examples illustrate how knowledge graphs could transform IKM.

3.3.1 Powerful and standardised IKM that enhances collaboration and learning

AI technologies are increasingly used for decision and process augmentation (Semantic Web Company, 2016). That is, they are employed to help knowledge workers to better connect their data – and to do so automatically. This promises to improve connectivity and support standardised knowledge management that can manage diverse content types and ensure that the connections are accurate. Amongst other processes combined knowledge graph-powered AI can (ibid., Blumauer and Nagy, 2020):

1. **automate tagging** of online content to **better connect relevant content** and reduce human error;
2. **automate classification** of content (e.g. by type, topic, quality);
3. **enable dynamic data connection/integration across databases and websites** via auto-tagging and content pool[16] development to facilitate **more efficient discovery, reduced fragmentation and website interoperability** with minimal admin;
4. **support collaboration** through identifying complementary activities based on text analysis of documents;
5. **drive highly tailored knowledge provision/decision-support tools** (Box 9);
6. **enhance** DataOps, a data management process that aims to improve the quality and reduce the cycle time of data analytics to promote collaboration, quality, security, access and ease of use; and
7. support **image recognition** and integration with other data (Marino et al. 2017).

These capabilities could transform so many aspects of how we learn and how much we learn. They could significantly enhance collaboration across disciplines and sectors (even where humans do not recognise a connection), and better **support the development of innovative, data-driven tools**, such as the H2020-funded I-REACT (Improving Resilience to Emergencies through Advanced Cyber Technologies) project.

16 Pooled data based on keyword-tagging.

3.3.2 Dynamic, responsive knowledge systems and decision-support tools

Combining knowledge graphs with AI technologies enables the development of knowledge systems that allow users to interact with and query machines much in the way that they would with a human expert. The use of **recommender systems**, "**chatbots**" and **automated helpdesks** can quickly link non-expert users to relevant content, and provide additional suggestions and recommendations with little effort or user knowledge of technical terminology (e.g. Morshed et al. 2013; Athreya et al. 2018). More advanced examples of these technologies include **natural language processing** question-answer systems and **collaborative decision support tools** that facilitate learning and reasoning about complex scenarios to **help answer complex, scenario-driven problems** (e.g. Lally et al. 2014; Catherine et al. 2016; Reddy et al. 2017). Tracking of user analytics can enable systems to **automatically tailor recommendations to users** based on their profiles and interaction with the system – as is commonly seen in the retail sector (e.g. Palumbo et al 2017). Such a system could thus be **adaptable to different stakeholders**.

In addition to supporting knowledge systems, these approaches could also be applied to complex knowledge-sharing and networking events such as the European Climate Change Adaptation conference and the Global Platform on Disaster Risk Reduction. These events, and those attending them, all face the challenge of **curating conference agendas and participation pathways that optimise learning**. Knowledge graph-supported AI technologies could be used to develop optimal agendas and user pathways that **maximise the potential for cross-discipline learning**. This would be particularly powerful for supporting engagement and learning in less-structured contexts such as side events at the Conference of the Parties.

3.3.3 A new level of data analysis

AI offers an opportunity to robustly and defensibly **identify patterns and convergences** across very large and diverse datasets and could be used to help **accelerate the translation of climate research into climate action**. Examples include analysing expansive datasets to develop **globally applicable indicators**, and learning more about **what measures work under different circumstances and why**. AI approaches are already used in systematic review, a process being increasingly applied in the environment sector to develop robust evidence for decision making (James et al. 2016). machine learning and other AI techniques used to expedite the data gathering process, which uses searches based on key terminology (e.g. Shackelford et al. 2020).[17] Through automatically connecting and analysing the relationships between key terms and data, knowledge graphs could further expedite and potentially enhance the systematic review process. With the inclusion of multiple languages, as in the Climate Tagger (see Box 5), taxonomies, ontologies and knowledge graphs can also support data analysis across content presented in **different geographical languages** as well as different technical terminology.

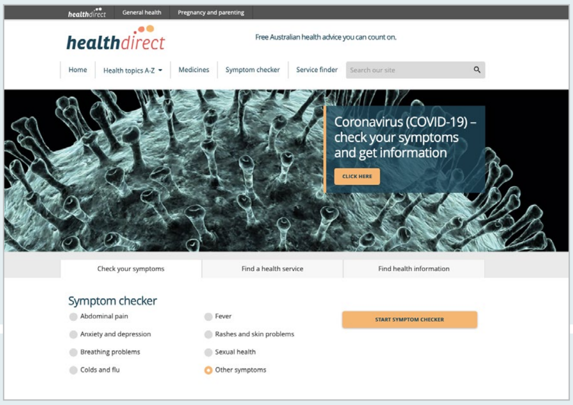
These analytical capabilities could also help us better **identify, understand and track the synergies, trade-offs, and coherence** of national and international plans, policies and frameworks, and do so automatically. For example, numerous tools are being developed to help decision makers understand and navigate synergies and trade-offs between the different international frameworks relating to climate change, disaster risk and development (Box 10). The analysis behind these tools is resource heavy and becomes quickly outdated as new plans and policies are published.

17 Resources for automation in systematic reviews.

Knowledge graphs and machine learning techniques present an opportunity to **automate analyses**, enabling their repetition over time. This in turn provides repeated opportunities to train the machine and improve the underlying knowledge models.

Box 9: Healthdirect Australia

The pharmaceutical and medical sector has pioneered the use of knowledge graphs.



The highly specialised information portal healthdirect Australia uses knowledge-graph technology to provide a harmonised entry point to free health and medical information derived from over 200 specialised information providers (Semantic Web Company, 2019).

In Australia information on health issues such as what different symptoms might indicate and best practice for treating injuries is available from hundreds of health-related information providers via a multitude of different platforms and websites. This makes it difficult for users to find high-quality, credible and useful information. As a result, citizens often use unofficial and illegitimate information to self-diagnose or attend hospital emergency rooms (ER) for non-urgent and minor health issues. This has resulted in high attendance rates that contribute to unnecessary costs and longer waiting times and overcrowding in the ER, which in turn can contribute to reduced quality of care.

Healthdirect Australia was built to address these issues through providing a single entry point through which Australians can access high quality, verified information. The website uses knowledge graph technology to harmonise and integrate data from the different information providers to provide improved services, including:

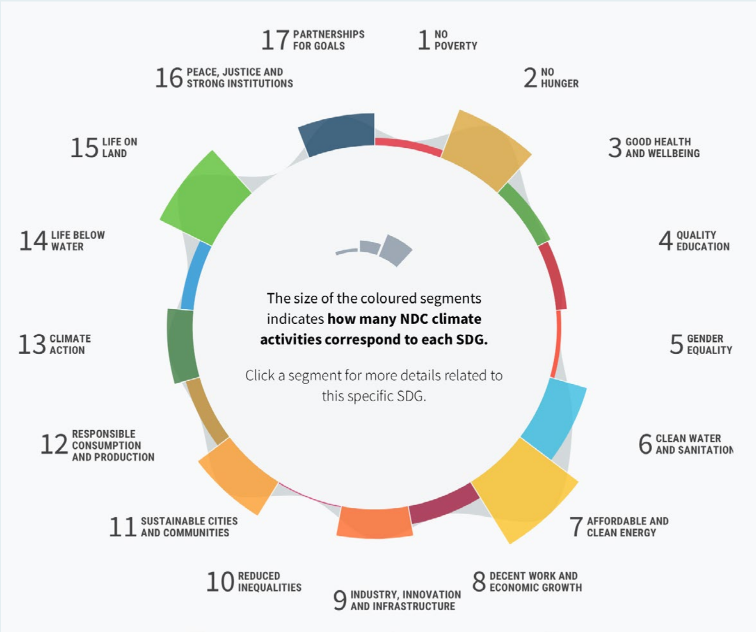
- improved search performance where searches return highly relevant multi-media content recommendations, even where the search term and the content description does not precisely match;
- a Symptom Checker employing a questionnaire that adapts dynamically to the user's answers to help them understand their symptoms and provide advice on what to do;
- a service finder providing access to Australia's most comprehensive directory of health services and providers that returns results based on location; and
- a faceted search and autocompletion of search queries to support non-experts to undertake specialised research.

The information providers also benefit from the single entry-point "content syndication" as healthdirect navigates users to their sites.

Box 10: The NDC-SDG Connections explorer

Nationally determined contributions (NDCs), under the Paris Agreement are statements of the actions countries intend to take to reduce greenhouse gas emissions, but many indicate other priorities and ambitions that contribute to broader sustainable development.

Tools such as the NDC-SDG Connections explorer[18] help stakeholders understand connections between Nationally determined contributions (NDCs)[19] and the Sustainable Development Goals (SDGs) through visualising the overlaps and potential synergies between the different international frameworks (in this case the Paris Agreement and the 2030 Agenda for Sustainable Development). The NDC-SDG Connections explorer is based on disaggregating each of the NDCs into "activities" (specific strands of future action under the NDC), which are then coded for their connections to each of the 17 SDGs and the 169 SDG targets. This process yielded more than 7000 activities (Dzebo et al. 2017; 2019).



Knowledge graphs and machine-learning techniques present an opportunity to automate such analysis. In this specific case, the existing coding of terms and their relations could provide a valuable foundation for the development of a "tracking" taxonomy/ontology to support and semi-automated analysis of future updates of the NDCs.

18 NDC-SDG Connections is a joint initiative of the German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE) and the Stockholm Environment Institute (SEI).

19 Nationally determined contributions (NDCs), under the Paris Agreement are statements of the actions countries intend to take to reduce greenhouse gas emissions, but many indicate other priorities and ambitions that contribute to broader sustainable development.

Chapter 4: A road map to transform IKM

It is one thing to understand what can be achieved with improved, harmonised IKM across the communities supporting climate action. It is another thing to understand how to get there.

This chapter presents a road map that provides a way forward to transform IKM. The steps outlined here will make the most of the vast array of climate-related knowledge scattered across various sectors, communities of research and practice, organisations, governments, and private sectors. This road map has been designed to enable us, as a community, to build on, further develop and integrate existing work across the climate action spectrum, to provide a global, integrated source of climate action data, information, and knowledge. This transformation promises to make knowledge more discoverable and more usable, and to connect relevant content across the Web. It has the potential to break down silos, and to empower generation of new knowledge through the powerful analysis of this connected dataset.

This road map is ambitious. Significant participation and collaboration sit at its core. This Chapter also describes a number of activities that can begin now, independently, to kick-start better practices, and to create an enabling environment.

4.1 A road map forward

To achieve the promise offered by IKM requires a shift in thinking about how to approach and undertake IKM. It requires the development of cooperation, governance, and quality assurance processes to support this shift. It requires:

- Widespread awareness of the value of IKM, both within and across institutions.
- Leadership from major actors to elevate and progress the agenda.
- Increased investment in information management to build capacity and IKM literacy.
- The collaborative development of authoritative, shared taxonomies and ontologies.
- Development and widespread adoption of standards for implementation.
- Creation of a governance model that allows for ongoing evolution.

The power of these technologies hinges on one investment: **participation**. Such technologies are effective only when implementation is widespread.

Developing and implementing the taxonomies, ontologies, and knowledge graphs at the level of quality and detail needed to maximise their potential will require significant collaboration, both amongst knowledge managers and experts in given fields.

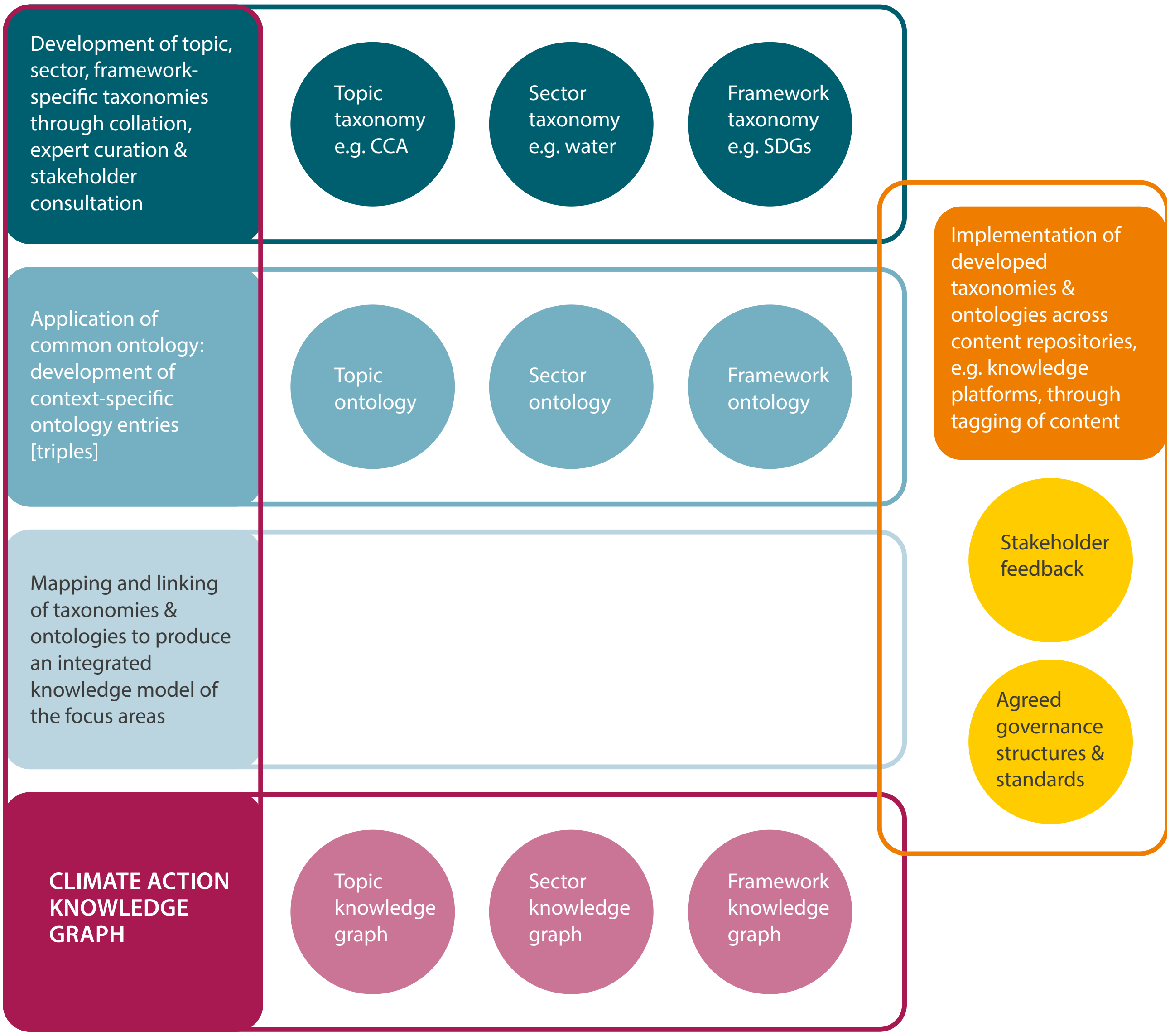


Figure 9: A road map for transforming IKM

This road map provides a way forward to transform IKM and work collaboratively to develop a Climate Action Knowledge Graph that incorporates the spectrum of focus areas relevant to climate action. Grey and blue boxes indicate key activities and outputs in the road map, respectively. Implementation of the taxonomies and ontologies across online repositories of content (data, information, knowledge) can be ongoing through the process and provides an opportunity to elicit further feedback and input from stakeholders and subject area experts. In this road map taxonomies provide an overview of terminology organised into a hierarchical structure and metadata for terms, including definitions and related terms. Ontologies are then used to classify terms according to their behaviour, e.g. 'participatory approach', 'climate impact', and type, e.g. 'author', 'project', 'adaptation solution', and describe how terms relate to each other, e.g. 'XX is a method used for XX'. The entire process is supported and directed by governance structures and standards agreed by the community of actors developing the taxonomies and ontologies for each topic, sector, and framework. Crucially, the building and extending of the Climate Action Knowledge Graph can be an interactive process, with subsequent mapping and linking activities as further taxonomies and ontologies are developed as well as expansion of the graph through machine learning approaches.

The road map presented here lays out a step-by-step process for relevant actors and initiatives to follow to develop shared taxonomies and ontologies that (1) describe existing and emerging areas of work relevant to climate action, and (2) set the stage for the development of a shared knowledge graph that links knowledge across these areas. Areas of work within the focus topics of CCA and DRR are: (1) sectors impacted by climate change (such as water, agriculture, urban development, finance and health); and (2) policy frameworks (the Paris Agreement, Sendai Framework for Disaster Risk Reduction, and the 2030 Agenda for Sustainable Development).

The road map consists of two parts. The first offers six concrete steps that knowledge and platform managers can take now. The second outlines sixteen steps for the medium and long terms.

Using the road map, actor groups focused on specific topics, sectors and frameworks collaborate to develop their own shared taxonomy and ontology (as has already begun, for example, through the FAO Agricultural Information Management Standards Portal (AIMS) and the UNDRR open-ended intergovernmental expert working group on indicators and terminology). These taxonomies and ontologies are then analysed for overlaps and appropriate linkages are made in consultation with the actor groups, and implemented in websites to produce an overarching climate action knowledge graph. Relevant actors and initiatives include those working on taxonomy and terminology (whether linked to knowledge management or decision-making), and knowledge management, in particular those coordinating knowledge platforms and websites. These actors will benefit from the support of IKM professionals, who can advise on and provide tools for the development of actionable taxonomies and ontologies that meet SKOS and OWL standards. The road map incorporates the work of Baur et al. (2016) (see section 2.3) on ways to create an integrated, unified view of heterogeneous knowledge relating to climate action.

This road map is ambitious. It requires strong leadership and extensive collaboration. However, a number of activities can begin now, independently, to kick-start better practices, and to create an enabling environment. Key actors that can support this process include but are not limited to the European Commission and High-Level Expert Group on Sustainable Finance, the Agricultural Information Management Standards Portal (AIMS) of the Food and Agricultural Organization of the United Nations (FAO), the United Nations Environment Program's (UNEP) Sustainable Development Goals Project (SDGIO) and the UNISDR Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction.

4.1.1 How to begin: steps to take now

Key players must push ahead with improving current IKM practices to leverage the vast knowledge already available. With this in mind, and taking inspiration from Baur et al. (2016), platforms, portals, projects, and organisations sharing content relating to climate action can already start preparing and contributing towards an integrated and unified view of heterogeneous knowledge relating to climate action by:

1. Following existing good practice principles and standards where possible. Examples of such measures include "open government" principles, World Wide Web Consortium (W3C) standards, and FAIR principles (Wilkinson et al. 2016); and for taxonomies and ontologies, the Simple Knowledge Organization System (SKOS) and Web Ontology Language (OWL) standards.

2. Sharing their existing taxonomies and ontologies (both formal and informal) with one another to support widespread uptake and use and provide an overview of the terminology being used in different focus areas and within different websites. Where possible, joint mapping exercises can be used to (1) "link" existing terms (concepts) between the taxonomies, and (2) expand metadata associated with terms (such as their synonyms).

3. Engaging experts to validate and improve taxonomies by adding missing terms, metadata and information on how the terms in the taxonomies behave and relate to each other (their semantics) to produce ontologies. Metadata can include definitions from each community on the use of terms, as well as "scope notes" that describe context-specific use (and importantly, excluded uses) to help non-experts understand and apply technical terms.

4. Adopting and implementing shared taxonomies and ontologies within their websites to tag content with relevant key terms. A free to use tagging tool, such as the Climate Tagger, which also enables retrospective tagging of large datasets, could support this step. Importantly, the use of synonyms for key terms allows for individualisation of terms used by different websites.

5. Developing application programming interfaces (APIs) to support interoperability and content sharing across websites. This is essential for crowd-sourcing, collating, and sharing pertinent knowledge.

6. Promoting awareness of the added value and importance of IKM within and across institutions in supporting knowledge uptake, informing decisions, and enabling powerful analysis using AI approaches. This is particularly important for those in senior leadership and those in a position to direct investments towards IKM.

4.1.2 How to advance: steps to take over the medium and long terms

The activities advocated here involve the development of taxonomies and ontologies that follow SKOS and OWL standards. They require specialised expertise. As such, an initial step for all actors involved is to assess current capacity and literacy for this work, and to engage with IKM (specifically taxonomy and ontology) professionals to address capacity gaps.

The collaborating groups of actors ("actor groups") must lead some of the steps by focussing on specific topics, sectors and frameworks (the "focus areas"). A wider community of actors must address other steps to contribute towards climate action.

Here we highlight each step according to the participation and leadership required: whether led by actor groups; addressed as a community; or a combination of the two.

Although presented here as a linear process, many of these activities can be undertaken in parallel and iteratively, enabling involvement of new actor groups at different stages. This process can emerge at different scales, for example within given sub-topics such as urban adaptation, ecosystem-based adaptation and community-based adaptation – all under the broader umbrella of the climate change adaptation agenda.

1. **Collate and evaluate existing taxonomies and ontologies in relevant focus areas (topic, sector, policy framework).** This requires actors to share existing taxonomies and ontologies (both formal and informal). Doing this will support widespread uptake of these taxonomies and ontologies, and provide an overview of the terminology being used in different focus areas and within different websites. It will also present an opportunity for different purveyors of online knowledge to learn about each other and each other's work, and explore potential collaborations.

   Result/output: a compendium of taxonomies and ontologies for the focus area, and a combined collection of terms that describes the focus area.

2. **Collate all the different data, knowledge and information types that the shared taxonomy and ontology need to describe and relate.** This can be done through surveying and exploring content currently being shared online, and paying attention to all the related fields. For example, international projects have related project descriptions, proposals, funding and donor information, details of the project team and associated organisations. This collation should also take into account useful labels for content management and decision-support (for example "climate impact", "methodology", "participatory approach") and relationships, such as those specifying the principles of particular approaches. An awareness of all of these different content types and labels will help inform their classification and relationships, and thus contribute towards a framework for a common ontology. Sharing this knowledge across focus areas will support others to think about the multitude of data, knowledge and information types that can be described.

   Result/output: a compilation of classifications and relationships that should be included in a common ontology.

3. **Conduct interviews and hold workshops with stakeholders to further explore the nature of content, terminologies and users' information and knowledge needs**, including the design of IKM systems and knowledge integration. Further exploring content and terminology will provide further input to the outputs of steps 1 and 2. A review of user needs (for example, regarding the data, information and knowledge needed, and the means needed to make these more accessible and usable) will further inform the structure of the common ontology and contribute to future steps. Note that this might highlight localised terminology and needs that could be captured in additional, context-specific taxonomies.

   Result/output: additions to the terminology developed in step 1 and compilation of classifications and relationships developed in step 2, and review of users' needs.

4. **Share, discuss and use outputs from steps 1-3 to explore significant overlaps in terminology and to establish components of a common ontology**. It is likely that many terms appear across the different terminologies (step 1). This presents an opportunity to check for overlaps, and explore how these terms are being used in the different focus areas. Where the same terms that are being used differently across the focus areas scope notes will be needed to help non-expert users understand these differences. Comparison of outputs from step 3 will identify what classifications and relationships should be included in a common ontology.

   Result/outputs:

   - **a list of highlighted terms for linking across the taxonomies,**
   - **an identified list of terms that require scope notes explaining how they are used and interpreted differently in the different focus areas, and**
   - **a list of components for a common ontology.**

5. **Specify a set of (prioritised) core IKM activities that taxonomies, common ontology and the resulting overarching knowledge graph should support**. This step should be informed by the user needs elicited in step 3. Example activities include managing content to support decision-making, data integration to yield significant new knowledge, and supporting website interoperability to promote content sharing across silos. This step helps to narrow the scale and focus the objectives of the taxonomies and knowledge graph. It also provides an evaluation framework that can be used continuously throughout the development phase and to direct future development.

   Result/output: a set of core IKM activities that this work should be able to support. These can be used to produce an evaluation framework for the taxonomies, ontologies, and knowledge graph.

6. **Agree on standards for quality assurance, metadata, and governance of the taxonomies, common ontology, and knowledge graph, and make key decisions about their licensing and publishing**. Simple Knowledge Organization System (SKOS) and Web Ontology Language (OWL) standards facilitate the development of quality, interoperable taxonomies, and ontologies. Additional standards can be used to (a) dictate what metadata should be included; (b) determine when terms should and should not be included in the taxonomy; (c) define who decides on structure, classifications and relationships, including minimum levels of user and expert participation to validate and legitimise the work, and how these decisions are made; and (d) designate how this is communicated to ensure transparency. Licensing and publishing decisions should support open data, shared ownership and widespread use of the taxonomies and ontologies.

   Result/output: a set of shared standards that ensure the quality and openness of the focus area taxonomies and ontologies being developed.

7. **Agree on standards for the implementation and use of the shared taxonomies and common ontology**. Taxonomies and ontologies can be used in different ways (for example, taxonomies for the manual tagging of online content, see Figure 1). Standards will help to ensure taxonomies and ontologies are applied accurately and in legitimate and useful ways, and that the content they link is of sufficient quality to be useful to users. These standards should focus on supporting Linked Open Data, enabling accurate clustering of knowledge for different decision-making contexts (e.g. geography, level of governance, policy relevance), and ensuring the relevance of connected data. Options include templates for assigning tags to content, and using taxonomy-based tagging tools to autotag content based on text analysis. Such standards are important for ensuring the quality of the ensuing knowledge graph and preventing misuse.

   Result/output: a set of standards to ensure the accurate and legitimate implementation and use of the shared taxonomies and ontologies.

8. **Develop a governance model that specifies how future changes and enrichments of the taxonomy and resulting knowledge graph will take place**. The focus areas will evolve over time and this will need to be reflected in the taxonomies and ontologies, for example with the addition of new terms and relationships. This can be supported by machine learning (see section 2.3). This step clarifies who is responsible for what, who makes decisions and how, what processes and methods are used (including for validation), and how frequent updates should be undertaken; it also defines the envisaged focus and scope of the work. Separate governance models and principles for cooperation between each of the focus areas and the resultant climate action knowledge graph, which integrates the focus areas, will likely be needed.

   Result/output: governance models describing roles and responsibilities regarding the ongoing development of the focus area taxonomies and ontologies, and the resultant climate action knowledge "graph of graphs".

9. **Develop a common ontology framework**. Drawing on step 4 and further informed by step 5 this common ontology framework describes all the classifications (for example, of methods and technologies) and relationships (for example, what approaches support what outcomes) that are useful to the wider climate action community, including knowledge managers, decision- and policy-makers, researchers, and practitioners. Where possible the ontology framework should build on existing relevant ontologies, for example, those used in publishing for classifying publications and authors.

   Result/output: a common ontology framework outlining the classifications and relationships that focus area actor groups should describe in their ontologies.

10. **Develop the focus area taxonomies and ontologies**. Drawing on outputs and standards from preceding steps, the core structure of the taxonomies can be developed. As far as possible this should incorporate the existing taxonomies within the focus area, using added metadata to capture synonyms and related terms, ensuring all terms used to describe the focus area are incorporated. Expert consultation can be used to validate, refine, and update the resulting taxonomy. In parallel, terms can be classified, and relationships defined using the common ontology framework, again using the input of experts to specify how the terms in the taxonomies relate to each other (their semantics) and to validate decisions.

    Result/output: focus area taxonomies and ontologies, co-produced with subject-area experts.

11. **Enrich and expand the taxonomies and ontologies**. Use text analysis of documents, websites, and other content to identify new terms for integrating into the taxonomy as well as identifying changes in meaning and semantics over time. Verify the addition of new terms and their placement, classification, and relation with existing concepts by consulting subject area experts.

    Result/output: up-to-date and enriched focus area taxonomies and ontologies.

12. **Add metadata to the focus area taxonomies**. Metadata can provide a rich base of information on the terms, including definitions and how they are used in different contexts (and, importantly, excluded uses) (see Box 4). Importantly, these notes help non-experts to understand the meaning and use of technical terms and how they are applied. The addition of metadata to the taxonomies can be informed by user needs (step 3) and core IKM activities (step 5), and supported by subject-area experts.

    Result/output: focus area taxonomies with detailed metadata.

13. **Analyse overlaps and, where appropriate, link the focus area taxonomies and ontologies to produce an integrated, shared climate action taxonomy and ontology**. Draw on overlaps initially identified in step 3. A mapping exercise can be undertaken to (a) "link" existing terms (concepts) between the taxonomies, mapping to broader, narrower and related terms where appropriate, and (b) expand metadata associated with terms such as their synonyms, definitions, and scope notes. This process will highlight where commonly used but differently interpreted terms (i.e. homographs) need to be delineated according to their usage so that appropriate tags can be applied when the taxonomies and ontologies are implemented. In such cases parenthetical qualifiers can be used to provide disambiguation (for example, Health (human), Health (ecosystem)). This complexity can be reflected in the scope notes for these terms. These can be cross-linked as related terms.

    Result/output: an integrated taxonomy and ontology describing and linking topic area, sectors, and framework relevant to climate action.

14. **Implement the integrated taxonomy and ontology in knowledge management systems.** The iterative and ongoing adoption and implementation of the shared taxonomies and ontologies within websites (for example, through tagging content with relevant key terms) – produces a well described, interrelated collection of knowledge – a knowledge graph. This could be supported through use of a free-to-use tagging tool such as the Climate Tagger (see Box 5), which also enables retrospective tagging of large datasets. Importantly, the use of synonyms for key terms allows for individualisation of terms used by different websites (see Box 4). Rolling out this technology in websites presents a further opportunity for continuous stakeholder feedback and input to the taxonomies through the suggestion of new terms. It also presents an opportunity to promote and communicate the taxonomy to stakeholders and others in the field.

> **Result/output: an integrated climate action knowledge graph.**

15. **Enrich and expand the taxonomies, ontologies, and overarching knowledge graph.** This iterative and ongoing activity can be directed by the governance models agreed in step 8. This could include regular updates in collaboration with each focus area and the use of supervised machine learning based on new and existing content and analytics. Links can be made to existing relevant and open taxonomies and databases such as DBpedia. Analysis and assimilation of search results and user feedback regarding existing, new, and alternative terms and their definitions, synonyms and scope of use will be important for ensuring quality.

> **Result/output: an enriched and expanded knowledge graph that provides a comprehensive overview of data, information, and knowledge.**

16. **Regularly test and evaluate the taxonomies, ontologies, and resulting knowledge graph and explore their potential to better support users, including through AI approaches.** Guided but not necessarily limited by the core activities and evaluation framework developed in step 5, the implementation of the taxonomies, ontologies and climate action knowledge graph can be explored and tested to see if it is facilitating the meeting of users' needs and enabling a new global, integrated view of climate action data, information and knowledge. Outcomes of this evaluation can be used to tweak development and governance processes, and to adjust existing and create new development and implementation standards and principles for collaboration. Case studies of how the technologies are being used can provide grounds for sharing lessons learned within the community on how the technologies can best be leveraged, and for further discussions on the potential opportunities – including AI-applications – provided by them.

> **Result/output: ongoing evaluation of the usefulness of the taxonomies, ontologies and climate action knowledge graph, improvement of development and governance processes, adjustment and addition of standards and collaboration principles, and sharing of lessons learned in the implementation of these technologies.**

The building and publishing of shared taxonomies and an overarching climate action knowledge graph sets the stage for researchers to leverage the latest in ICT, including AI approaches, to develop new insights and support policy processes, and for organisations and platforms to share their content through new gateways, such as the Connectivity Hub (see Box 6) that make it easier for people to find and understand relevant information – and for information producers to extend their reach and impact.

To realise the full potential of this technology we, as a community, must work more closely with users (policy advisors and researchers) to understand needs, and to invest in technological development to meet these needs (for example, the development of dynamic, interactive and responsive systems that leverage knowledge graphs that allow users to find the content they need, and to discover additional relevant content they may not have realised that they needed). This should include engaging with and facilitating research to (a) explore how different content and databases can be combined and analysed using knowledge graphs and artificial intelligence techniques, and (2) develop applications that use knowledge graphs to support and drive learning.

4.2 PLACARD: the proof of the concept in action

PLACARD has initiated the development of integrated taxonomies and ontologies for climate change adaptation and disaster risk reduction. These are based on expert input, existing keyword tags coming from knowledge platforms participating in the PLACARD Connectivity Hub (see below), the text mining of key international documents including the IPCC reports and Sendai Framework for Disaster Risk Reduction, and key planning documents such as the EU Adaptation Strategy. These taxonomies will be published on the PLACARD website and made available through the Climate Tagger (Box 5), a free to use tagging tool that website developers can integrate to initiate the linking of relevant content from across these two climate-relevant areas of research, practice, and policy.

PLACARD has also developed the Connectivity Hub (Box 6), which makes content from multiple online platforms available in one space to help reduce incidences of redundancy and replication that may arise from a lack of awareness of parallel and complementary work. It enhances collaboration by reducing the often-siloed nature of both the adaptation and disaster risk communities. The Connectivity Hub could be a testbed not only for the PLACARD-developed taxonomies, but also for the use of artificial intelligence, knowledge graphs, and machine learning to produce new, policy-relevant insights. The Hub is designed to help planners, decision-makers, researchers, policymakers, students, and interested citizens. It aims to avoid redundancies, wasted resources and the tendency to unnecessarily reinvent the wheel – which can happen when people are not aware of parallel or complementary work elsewhere. Therefore, the Hub helps actors find information that they may not know exists, and that they may not know they need. And it helps people to find this information quickly and easily. Semantic tagging and linked data, using knowledge-graph approaches, could transform online knowledge discovery, making the PLACARD Connectivity Hub more powerful, and enabling it to tailor support to different users in "smart" ways. Bringing together the climate change adaptation and disaster risk reduction sectors in ways that foster better collaboration and unified views across their two communities and missions offers an excellent showcase for the utilitarian potential and power of knowledge-graph technology.

4.3 Key messages

1. To an unprecedented degree, people are generating huge amounts of data, information, and knowledge for two key, global missions: addressing climate change, and achieving the sustainable development goals. Harnessing and leveraging such information are urgent tasks. They are within our grasp. They require a new mindset, investment in key management practices, and the collective will to operate in ways that make finding and sharing information easier.

2. The status quo does not meet the world's needs. Individual operations work independently without universal standards that connect related work across the globe. Previous efforts to classify, categorise and structure climate-relevant knowledge as needed have failed to reach their full potential – or their intended audiences. As a result, people cannot easily and rapidly find the information they seek.

   When they do find information, they often cannot understand it – and thus cannot use it. In such an environment, people around the world cannot learn from one another's experiences, policies, and research, or from successes and failures.

3. The basic, often overlooked organisational practice of Information Knowledge Management (IKM) offers a viable way forward. Such management practices can make possible the exchange of knowledge needed to meet the scale of these challenges. IKM technologies at hand and on the horizon have the power to connect and analyse vast amounts of climate-relevant data and information in ways that previously were not possible. Leveraging these technologies can make data, information, and knowledge "FAIR" – that is, findable, accessible, interoperable, and reusable.

4. Technology offers unprecedented opportunity, but it cannot solve the problem on its own. A single organisation cannot solve the problem on its own, either. Success requires global cooperation and coordination. Progress largely hinges on the adoption and use of universal, standardised IKM practices by relevant organisations, governments, the private sector, civil society, and the research community. Some standards already exist; others must be developed.

5. The advent of the IKM technologies and the use of practices outlined in this paper can transform the Internet into a true global database that is up to the global missions at hand. The use of these tools and practices can lay the foundation for further advances from artificial intelligence (AI) approaches now on the horizon. As its use in other fields already demonstrates, AI can yield new insights and knowledge. Leveraging AI in the future requires that changes in management practices begin in the present. Absent the widespread adoption of IKM tools, practices and standards, the climate change agenda will be ill equipped to take advantage of the new analytical power of next-generation tools.

6. This paper serves as a siren call for greater leadership and funding, and for summoning the collective will to create a step change in the prevailing conduct of fundamental IKM practices. Such measures need and deserve greater attention and investment to achieve their potential to serve the global climate and sustainable development agendas.

Glossary

Artificial intelligence – intelligence demonstrated by machines, in contrast to the natural intelligence displayed by humans and animals. Artificial intelligence (AI) makes it possible for machines to learn from experience, adjust to new inputs and perform human-like tasks. Machine learning is a branch of artificial intelligence. See SAS Insights.

Climate action – stepped-up efforts to reduce greenhouse gas emissions and strengthen resilience and adaptive capacity to climate-induced impacts, including: climate-related hazards in all countries; integrating climate change measures into national policies, strategies and planning; and improving education, awareness raising and human and institutional capacity with respect to climate change mitigation, adaptation, impact reduction and early warning. See Sustainable Development Goal 13.

Deep learning – a type of machine learning that trains a computer to perform human-like tasks, such as recognising speech, identifying images or making predictions. See SAS Deep learning.

Information and knowledge management (IKM) – the systematic process of collating and sharing data, information and knowledge so that it can be easily found, accessed and used.

Interoperability – the ability of a product or system "to work with other products or systems, at present or in the future, in either implementation or access, without any restrictions" (adapted from Interoperability definition), for example by encoding data and related information using a standard that can be read on all applicable systems (EC, 2018).

Keyword-tagging – assigning keyword tags to a piece of information (such as an Internet bookmark, digital image, database record, or computer file). This kind of metadata helps describe an item and allows it to be found again by browsing or searching.

Knowledge (computer science) – connected information that is "query ready". See Medium article).

Knowledge graph – a fabric of concepts, classes, properties, relationships, and entities covering multiple domains, various levels of granularity, and data from multiple sources. It functions as background knowledge for various applications (e.g. question answering, data integration and machine learning). See Semantic Web Company.

Linked (Open) Data – structured data which are interlinked with other data so they become more useful through semantic queries. Linked Open Data (LOD) refer to Linked Data that are released under an open license, which does not impede free reuse of the data (Berners-Lee, 2006).

Machine learning – a method of data analysis that automates analytical model building. It is a branch of artificial intelligence based on the idea that systems can learn from data, identify patterns, and make decisions with minimal human intervention. See SAS Insights.

Metadata – data that provide information about other data. See Merriam Webster.

Natural language processing – a subfield of linguistics, computer science, information engineering, and artificial intelligence concerned with the interactions between computers and human (natural) languages, in particular how to program computers to process and analyse large amounts of natural language data. See Wikipedia.

Ontology (information science) – a representation, formal naming, and definition of the categories, properties, and relations between the concepts, data, and entities that substantiate one, many, or all domains of discourse. More simply, an ontology is a way of showing the properties of a subject area, and how they are related, by defining a set of concepts and categories that represent the subject. See Wikipedia.

Scope notes – metadata that can be added to a taxonomy to provide background on how terms are used and how they have evolved over time. This is important for helping non-experts understand and navigate terms used by multiple communities of practice but with differing interpretations.

Semantic Web (also called Web of Data) – an extension of the Web through standards developed by the World Wide Web Consortium (W3C) that promote common data formats and exchange protocols on the Web. The goal of the Semantic Web is to make Internet data machine readable.

Systematic review – a type of literature review that uses systematic methods to collect secondary data, critically appraise research studies, and synthesise findings qualitatively or quantitatively. Systematic reviews are designed to provide a complete, exhaustive summary of current evidence, published and unpublished, that is "methodical, comprehensive, transparent, and replicable.

Taxonomy – the practice and science of categorisation based on discrete sets. In knowledge management a taxonomy is a hierarchical structure or order of terms of a knowledge subject that supports content organisation and retrieval. See Wikipedia, Semantic Web Company, Wikipedia (taxonomy), Wikipedia (corporate taxonomy).

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