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Climate Change TimeLine: An Ontology to Tell the Story so Far

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ABSTRACT In this paper we present an ontological approach to build a knowledge-base on climate change related facts. Our knowledge space, developed in Ontology Web Language (OWL), enables knowledge within the Semantic Web. It allows a dynamic classification and a semantic characterization of the different events that can be related to each other, as well as to external sources of information. The resulting ontology is structured as a timeline which aims to describe the climate change story from multiple perspectives, including scientific, social, political and technological ones. We have created an instance of the ontology as an attempt to tell the climate change story so far. Such a population is based on the collection of factual information and critical literature review, with a focus on relevant theories, happenings, social and political initiatives. In this paper we present an ontological approach to build a knowledge-base on climate change related facts. Our knowledge space, developed in Ontology Web Language (OWL), enables knowledge within the Semantic Web. It allows a dynamic classification and a semantic characterization of the different events that can be related to each other, as well as to external sources of information. The resulting ontology is structured as a timeline which aims to describe the climate change story from multiple perspectives, including scientific, social, political and technological ones. We have created an instance of the ontology as an attempt to tell the climate change story so far. Such a population is based on the collection of factual information and critical literature review, with a focus on relevant theories, happenings, social and political initiatives.

INDEX TERMS Climate change, ontology, OWL, semantic web, knowledge management.

I. INTRODUCTION

Climate change is a threat to all lives on Earth, yet very little is being done to address the issue at hand. Despite anthropogenic climate change being a fact from a scientific perspective, the science behind climate change is still disputed [1].

In simplistic terms, the concept ''climate change'' indicates, according to Climate Change in Australia, a prevailing change in climate statistics such as temperatures, greenhouse gases and sea levels [2]. This can occur due to natural phenomena, as well as due to human activities [3].

More recently, climate change has often been associated with changes in the amounts of greenhouse gases due to human activities that have resulted in a steady increase in temperatures [4]. This rise in temperatures has set off a series of ecosystem alterations resulting, for instance, in the melting of icebergs in the Arctic and Antarctic, rising sea levels, an increase in storms and calamities, and the destruction of natural habitats leading to wildlife extinctions [5]. Anthropogenic climate change is on the verge of disrupting our lives as we know it [6].

Climate change emergency is considered to be the no.1 threat to humanity at the moment. However, the actions taken in response are considered far away from the needed to assure sustainability. Indeed, the science of climate change itself is often disputed, and there are people who disbelieve its validity [7]. Establishing policies to address climate change implies the need for global agreements, as well as a strong commitment by local governments. This, evidently, is a major challenge for humanity, while global warming continues to break records [8].

More recently, climate change has been gaining attention in the public debate because of Greta Thunberg,[1] a young Swedish environmental activist who has been promoting worldwide demonstrations to ask governments for concrete action. Greta's activity has generated an enormous

The associate editor coordinating the review of this manuscript and approving it for publication was Malik Jahan Khan.

[1]Wikipedia - Greta Thunberg, https://en.wikipedia.org/wiki/Greta_Thunberg. Accessed: 6 January 2020.

consensus but, unfortunately, also some criticisms and denigrating attacks.

The climate change story has already been making headlines, the next chapters of which will probably define the future of our planet in the context of anthropogene [9]. However, the climate change story is defined by the progressive convergence of a number of theories rather than by a linear collection of simple facts. Although in many cases, such theories have been supported by clear scientific evidences, climate change has never been considered an actual priority despite their objective relevance and practical impact in our lives. However, a social awareness around climate change is quickly rising. We believe that at this stage it is extremely important to tell the story so far allowing multiple interpretations and perspectives. Indeed, the climate change story cannot be limited to scientific perspectives, but needs to be understood in the light of social and political contexts as well; it has to be analysed taking into account other aspects of life, such as inequities and inequalities.

In this paper we present an ontological approach to build a knowledge-base on climate change related facts. Our knowledge space, developed upon Semantic Web technology, enables knowledge within the Semantic Web [10], assuming, therefore, a Linked Data philosophy [11]. It allows a dynamic classification and a semantic characterisation of the different events that can be related to each other, as well as to external sources of information. The resulting ontology (CCTL) is structured as a timeline which aims to describe the climate change story from multiple perspectives, including scientific, social, political and technological ones. We have created an instance of the ontology based on critical literature review and on the collection of factual information from relevant sources as an attempt the tell the story so far with a focus on most relevant theories, happenings, social and political initiatives. Such a data infrastructure is significantly more consistent than a simple specification of ordered facts. Last but not least, the proposed ontological approach focuses on the backbone of the semantic structure, namely on the systematic definition and integration of climate change related facts as part of a unique knowledge base. Such approach is agnostic with respect to the domain vocabulary. It can be an external vocabulary, as well as it can be collaboratively defined by users or inferred by the semantic analysis of referred documents.

As the climate change story is complex and diversely articulated, we do not pretend to provide a comprehensive set of facts and events. The focus of this research is on the ontological model to describe climate change facts which can be semantically enriched and defined in a given context through internal and external linking.

A. METHODOLOGY AND APPROACH

The ontology described in the paper has been developed by following an iterative process composed of the following steps:

- *Development of an ontological structure to define a timeline of potentially correlated events*. This very first stage aimed to provide a simple agile data structure to arrange events, facts, data and theories along the time dimension. At this stage, correlations are completely generic as more specific relationships are expected to be introduced by users within the different application domains.
- *Primary classification of climate change related facts and happenings*. In order to better organise the target knowledge, we have provided a primary classification for climate change related facts and, additionally, some more fine grained concepts. As usual in knowledge engineering, this base taxonomy is expected to evolve according to the users' needs. We have also provided a generic class that identifies an element of the timeline. It allows to skip the use of the taxonomy in case such classification doesn't match needs in a given application context.
- *Population of the ontology based on literature review and the analysis of recent facts*. We have generated an instance of the ontology from a literature review and recent facts analysis. Such a population doesn't pretend to include all relevant facts, happenings and theories. It rather aims to provide a base dataset to evolve by integrating contributions by users from different areas of expertise.
- *Semantic enrichment by identifying correlated concepts*. The instance of the timeline defined in the previous step has been enriched by identifying correlations among the different timeline elements. Such correlations have been described by adopting the provided vocabulary.
- *Validation and consistency checking within well-known development environments*. Finally, we have checked our implementation within well-known ontology development environments with the support of reasoners, query wrappers and visualization tools. Details are provided later on in the paper.

B. STRUCTURE OF THE PAPER

The paper follows with a related work section. The core part is composed of two sections that deal with the description of the ontology (sec. III) and of climate change timeline (sec. IV) respectively. The former section focuses on the vocabulary by providing an overview of main concepts and relationships existing among them, as well as some details about the ontology implementation. The latter presents the ontology population by describing some key facts related to climate change. Moreover, it includes examples of specifications by adopting the ontological format provided, and examples of complex query on the resulting semantic structure. The paper ends with a conclusion section, which also addresses potential future work.

II. RELATED WORK

In this section we discuss the importance of narratives and public perceptions in the climate change issue, both with the adoption of ontologies to describe the different aspects of climate change.

A. NARRATIVES AND PUBLIC PERCEPTIONS

The climate change story is definitely a controversial one, making headlines and raising consciousness at different social levels, including elites (e.g. politicians and decision makers) and common people [12]. In this process of progressive awareness, narratives play a relevant role [12] and may influence public perceptions [13]–[15].

A well recognised influence can be celebrity endorsements. Indeed, public figures have a wide audience reach and, in general, they can potentially act as influencers among followers. On the negative side, associating the climate change issue with a public figure can cause a perception of climate change as part of the figure's brand [16]. Thus, the narrative is swayed by what the figure portrays rather than being based on indisputable facts and on a real awareness of the problem.

Timelines are effective to summarize narratives and are extensively used in different works, for example in *The Discovery of Global Warming*[2] [17]. In [18] authors highlight some notable developments along time in the creation and use of emissions, as well as other timelines (e.g. on globalization [19]) may indirectly deal with climate change.

Historically, news outlets largely communicated climate change topics as one of scientific significance [20]. However, the media often prioritize news that may easily catch the attention of people, i.e. sensationalist news. Indeed, news that may have an impact on people's lives in a relatively long term are often not even perceived as ''real'' news. That has an impact on how people perceive the reality of climate change.

Survey and poll data normally help to understand the impact of such influences on public perceptions, and to measure the effective level of awareness among people. Studies such as the one by [21] show that public knowledge gained traction around the late 1980s where up to 70% of respondents were aware of climate change; this was a marked improvement from early 1980s where only about 30% of respondents were aware of climate change. However, according to those studies, the actual knowledge was limited. Through the 1990s, awareness and understanding of impacts of climate change improved, but a lack of knowledge of what causes climate change persisted through to the millennium. To this day, the human contribution to climate change is disputed to the point that even the reality of climate change is disbelieved by many.

An effective awareness of climate change and its effects on human life is progressively building and demands clear response (e.g. for public health [22]) by governments [23].

We model our dataset and, therefore, our knowledge space as a timeline, meaning we consider the time dimension to organize the target knowledge. However, as it will be extensively explained later on in the paper, the ontological approach intrinsically supports multi-dimensional data and complex query from different perspectives.

B. ONTOLOGIES FOR CLIMATE CHANGE

Because of its complexity, climate change is unlikely to be entirely described by one single ontology [24]. Indeed, an ontology that fully addresses climate change should include concepts from various disciplines, implicitly assuming pluralism [24]. For instance, the semi-automatic method proposed by [25] allows the progressive extension of the concept hierarchy from a seed ontology by mining textual data from the Web sites. More in general, a collaborative approach assures effectiveness in building large scale knowledge bases [26]. In [27] the authors deal with technoscientific ontologies of climate change. In [28] authors adopt an ontological approach to evaluate the impact of a changing climate on food and waterborne diseases. Ontology has been adopted to model the impacts of agriculture and climate changes on water resources [29]. An ontology based on nature-society mutuality is adopted to deal with adaptive living with climate change in the rural areas [30]. An interesting application of ontology is to track the provenance of information [31].

As far as we know, there is no ontology to support the description of climate change related facts and their integration with contextual information. The ontology proposed in this paper aims to build a climate change timeline by adopting an approach which is agnostic with respect to the domain vocabulary. Indeed, the ontology primarily addresses the definition of the timeline backbone, namely the specification and the correlation of climate change related facts. Such facts and events are dynamically classified, meaning the underlining taxonomy provided is expected to evolve as per users' need. Similarly, the domain vocabulary, which is not object of this paper, may be created by merging external vocabularies from different disciplines, as well as it can result from the analysis of referred documents. We have chosen this open approach because of the intrinsic transdisciplinarity that characterises climate change. This heterogeneity makes hard a centralised definition of a domain vocabulary, and advises a ''local'' approach closely related to the various disciplines. Moreover, the characterization and semantic enrichment of described facts is based on external linking over the Semantic Web infrastructure. It allows the understanding of climate change related facts within a rich context as a result of the association with content on the Web. Additionally, the adoption of Semantic Web technology facilitates information re-use and interoperability. Therefore, the specifications provided may be easily integrated within generic purpose knowledge bases (e.g. DBpedia [32]).

III. CCTL ONTOLOGY: DESCRIBING CLIMATE CHANGE RELATED FACTS

The *Climate Change TimeLine (CCTL)* is an OWL ontology[3] to describe climate change related facts. It has been developed

[2] The Discovery of Global Warming, https://history.aip.org/climate/index.htm. Accessed: 10 September 2019.

[3] OWL 2 Web Ontology Language Document Overview (Second Edition), https://www.w3.org/TR/owl2-overview/. Accessed: 23 September 2019.

TABLE 1. Main classes.

Class	Sub-class of	Description
ClimateChange_Fact	-	Generic fact or happening related to climate change.
SocialAwarness	ClimateChange_Fact	Fact or happening directly related to social awareness about climate change.
ScientificEvidence	ClimateChange_Fact	Scientific evidence or finding related to climate change.
PoliticalInitiative	ClimateChange_Fact	Political initiative (e.g. policy or regulation) related to climate change.
Theory	ClimateChange_Fact	Theory (supported by scientific evidences or not) related to climate change.
Technology	ClimateChange_Fact	Technology with a positive or negative impact on climate change.
Happening	ClimateChange_Fact	Happening associated with climate change (e.g. a glacier disappearing).
Demonstration	SocialAwareness, PoliticalInitiative	Demonstration for climate change.
Policy	PoliticalInitiative	Policy as in a common meaning.
Impact	-	Impact of a given technology from a climate change perspective.
Year	-	Year as in a common meaning.
Reference	-	Reference as in a common meaning.
Organization	-	Organization as in a common meaning.
PolicyScope	-	Scope (e.g. national, trans-national) of a given policy.

TABLE 2. Subset of data and annotation properties.

Property	Property Type	Domain/Range	Description
relatedTo	Object Property	ClimateChange_Fact / ClimateChange_Fact	Generic relationship between two climate change related facts.
description	Data Property	ClimateChange_Fact / -	Description associated with a climate change related fact.
year	Object Property	ClimateChange_Fact / Year	Year associated with a climate change related fact.
year_s	Data Property	ClimateChange_Fact / -	Year as in the previous definition expressed as a Data Property.
startYear	Object Property	ClimateChange_Fact / Year	Starting year to define a time range associated with a climate change related fact.
startYear_s	Data Property	ClimateChange_Fact / -	Starting year as previously described expressed as a data property.
endYear	Object Property	ClimateChange_Fact / Year	Ending year to define a time range associated with a climate change related fact.
endYear_s	Data Property	ClimateChange_Fact / Year	Ending year as previously described expressed as a data property.
reference	Object Property	ClimateChange_Fact / Reference	Reference to a content (e.g. scientific literature or newspaper article).
impact	Object Property	Technology / Impact	Impact (positive, negative or neutral) associated with a technology.
adoptedBy	Object Property	Policy / Organization	It relates a given policy to the organization that adopts or proposes it.
policyScope	Object Property	Policy / PolicyScope	It relates a given policy to its scope.
citation	Data Property	Reference / -	Citation associated with a given reference.

with the support of Protege[4] [33] and validated within that same environment by adopting common reasoners, such as PELLET [34] and HermiT [35]. Main classes are reported in Table 1, while properties are listed in Table 2.

An overview of the ontology is depicted in Figure 1. It is structured in three ideal layers, including a main categorization, a secondary categorization and a set of supporting concepts. These three layer are separately described below.

A. MAIN CLASSIFICATION

Because of its specific purpose, CCTL is designed around the central concept of climate change related fact (*CCTL:ClimateChange_Fact*). Such a class represents the most possible generic concept and it is used to classify a generic fact.

Primary classification assumes five different sub-classes (fig. 1) as follows:

- *Scientific Evidence*. It is some scientific evidence, normally documented in literature.
- *Social Awareness*. It differs from the previous one because it is related to an evidence or event directly associated with social awareness about climate change.
- *Political Initiative*. Any kind of political initiative directly or indirectly related to climate change.
- *Theory*. Theory on climate change, i.e. a prediction of a future happening or event due to climate change. As a theory may or may not be supported in the real world by some factual evidence, we prefer to differentiate such concept from the previously mentioned scientific evidence.
- *Technology*. A technology that has an impact (*CCTL:Impact*), positive, negative or neutral, on climate change. As we are implicitly focusing on climate change caused by human activity, the progress and, therefore, the underpinning technology plays a central role.
- *Happening*. An event related to climate change (e.g. a glacier disappearing). In many cases, it can be considered equivalent of the generic fact. It normally refers to events.

Facts can be related to each other with the generic relationship *CCTL:relatedTo*. This is similar to the omonymous property in PERSWADE-CORE [36], but it is stated as a symmetric property as per OWL specification:

[4] A free, open-source ontology editor and framework for building intelligent systems, https://protege.stanford.edu. Accessed: 23 September 2019.

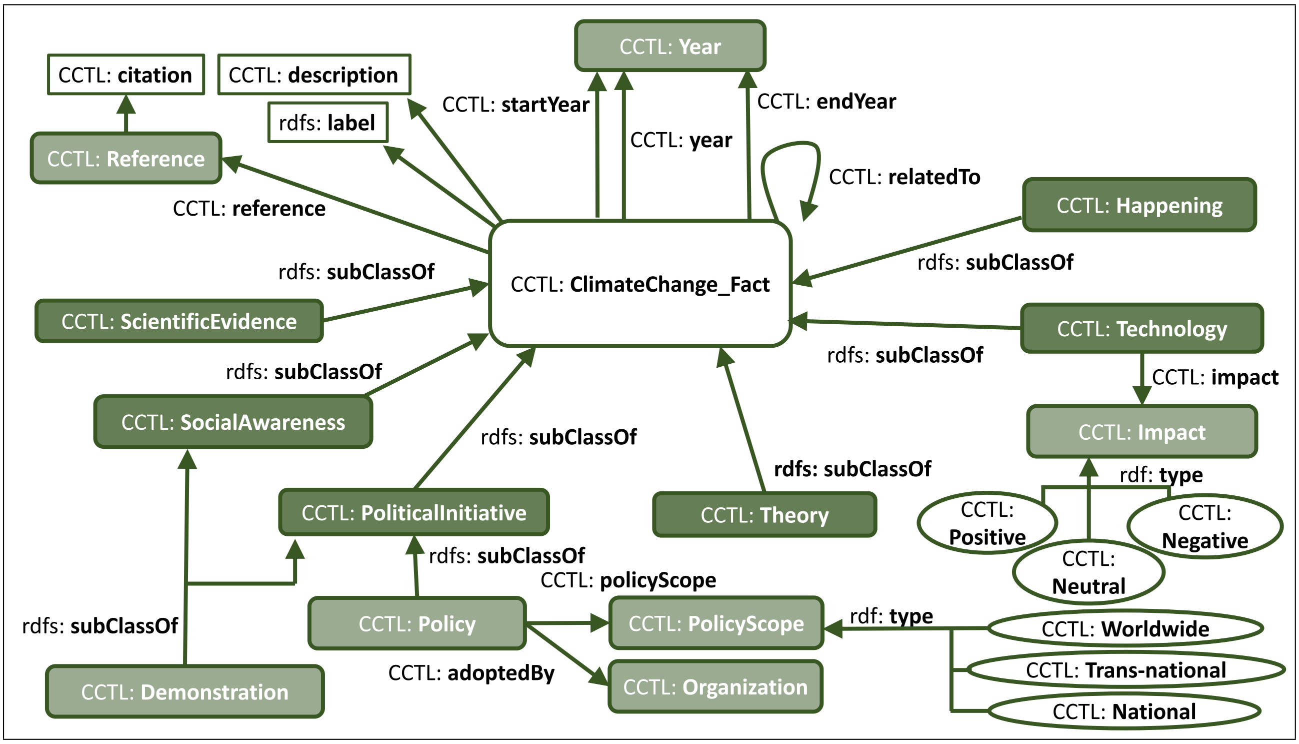


FIGURE 1. CCTL ontology overview.

```
CCLT:relatedTo
            rdf:type owl:ObjectProperty ,
                     owl:SymmetricProperty ;
            rdfs:domain CCLT:ClimateChange_Fact ;
            rdfs:range CCLT:ClimateChange_Fact .
```

This generic relationship provides a simple, yet effective, way to navigate the resulting knowledge graph from an event correlation point of view. Sub-properties to define more specific relationships among facts will be object of future work.

B. SECONDARY CLASSIFICATION

Ontologies are formal descriptive tools [37] that are extensible by definition. Thus, a core taxonomy can evolve according to users ' needs.

Our core taxonomy has been extended to include two very common concepts, demonstration (*CCTL:Demonstration*) and policy (*Policy*) as in a common meaning. The former is understood as a sub-class of both *CCTL:SocialAwareness* and *CCTL:PoliticalInitiative*, as we consider significant demonstrations to have an impact at both a social and political level. The latter is assumed to be a kind of political initiative. A given policy is normally associated with a scope (*CCTL:PolicyScope*) - i.e. national, trans-national, worldwide - as well as with the organization which proposes or adopts it.

C. SUPPORTING CONCEPTS

Regardless of its generic or fine-grained classification, each fact assumes a description in a natural language (*CCTL:decription*) and a label (*rdfs:label*).

Additionally, the time dimension is modelled as a relationship to a single year (to be specified through the property *CCTL:year*) or to a year range defined by a starting and ending year (*CCTL:startYear* and *CCTL:endYear* respectively). The association of a given event with the time can also be specified by using the corresponding data properties (*CCTL:year_s*, *CCTL:startYear_s* and *CCTL:endYear_s*). Generally speaking, that level of detail is considered appropriate to build the target timeline. A more sophisticated association with time may rely on specific ontologies (e.g. *Time Ontology in OWL*[5] by W3C).

In order to build a consistent knowledge space, facts should be always associated with proper references, typically scientific literature, newspaper articles, reports, datasets or Web content. Because of the characteristics of ontological data models, this kind of link becomes a critical factor to build effective knowledge graphs. Normally a reference is identified by a URL or identifier (e.g. the DOI[6]). Further info, the full citation (*CCTL:citation*) for instance, may be associated with references.

IV. THE CLIMATE CHANGE TIMELINE

The current version of the timeline includes the events reported in table 3, 4, 5, 6, 7, 8, 9, 10 and 11. Each table refers to one of the main categories for events classifica-

[5]Time Ontology in OWL, https://www.w3.org/TR/owl-time/. Accessed: 25 September 2019.

[6]Digital Object Identifier, https://www.doi.org. Accessed: 26 September 2019.

tion as previously discussed. Events related to technology (Table 11) are limited to ICT in the current version of the ontology. The ontology is represented as a knowledge graph in figure 2.

In the following subsections, we focus on examples of use. We first provide an example of project descriptor by using an external vocabulary. In general, a project descriptor allows to specify metadata and generic information about a given project and, eventually, to register it within a target system. The descriptor normally depends on the target system. Our example is based on the PERSWADE-CORE model [36]. Additionally, we provide an example of formal specification of events by adopting the ontology. Finally, we propose some examples of complex query.

A. PROJECT DESCRIPTOR

A project descriptor is provided by adopting PERSWADE-CORE ontology [36]. The specification of the most relevant aspects, including project provenance, method adopted, main deliverables, aim and scope and similar concepts is depicted in fig. 3.

Such a descriptor is defined by the following OWL code (turtle syntax):

```
perswade:ClimateChange_Timeline
 rdf:type owl:NamedIndividual,
           perswade:Research_Project;
 perswade:developed_within perswade:PERSWADE ;
 perswade:adopts_method perswade
 :Conceptual_Modeling;
 perswade:aims_at perswade:Sustainability;
 perswade:contributes_to perswade:ClimateChange;
 perswade:delivers perswade:CCTL_ontology,
           perswade:ClimateChangeTimeline_Dataset;
 perswade:description ``........'' ;
 perswade:year 2019.
```

B. EXAMPLES OF SPECIFICATION ADOPTING CCTL

An example of specification involving 3 different events is proposed in fig. 4.

The first fact is a theory proposed in 1968 by Mercer. He predicted that a relatively slight rising of temperature could lead to the melting of the West Antarctic Ice Sheet which would in turn raise sea levels by about 5 metres [38].

The formal specification in OWL is as follows:

```
CCTL:MercerPrediction
  rdf:type owl:NamedIndividual ,
         CCTL:Theory ;
  CCTL:reference .... ;
  CCTL:year  CCTL:1968 ;
  CCTL:description ``...'' .
```

A second fact is related to Okjökull (Ok glacier) that was declared dead in 2014[7]. The fact is considered to be correlated to the previous one as an old theory has somehow predicted a happening.

The code is reported below:

```
CCTL:Okjokull_dead
  rdf:type owl:NamedIndividual ,
         CCTL:Happening ;
  CCTL:reference ... ;
  CCTL:relatedTo CCTL:MercerPrediction  ;
  CCTL:year  CCTL:2014 ;
  CCTL:description ``...'' .
```

Finally, we consider a recent (2019) demonstration in Iceland where a number of activists celebrated the funeral of that same glacier. Such a demonstration has been reported by media worldwide, for instance by SBS News.[8] The fact is intrinsically correlated to the previous one.

The formal specification is proposed below:

```
CCTL:Okjokull_funeral
   rdf:type owl:NamedIndividual ,
         CCTL:Demonstration ;
   CCTL:relatedTo CCTL:Okjokull_dead;
   CCTL:reference ... ;
   CCTL:year CCTL:2019 ;
   CCTL:description ``...'' .
```

C. EXAMPLES OF COMPLEX QUERY

Apart from automatic reasoning by inference, developing upon Semantic Web technology assures full support to complex query through standard languages, i.e. SPARQL.[9]

Few simple examples of SPARQL query on the proposed ontology are:

- *All correlated facts*. By executing the SPARQL code reported below, all facts that are related to others are retrieved.

```
SELECT ?x ?y
WHERE {
       ?x CCTL:relatedTo ?y
     }
```

- *All facts related to a fact that happened in a given year*. The query reported below is an elaboration of the previous one that retrieves facts related to a fact that happened in a given year.

```
SELECT ?year_x ?x ?year_y ?y
WHERE {
       ?x CCTL:relatedTo ?y.
       ?x CCTL:year CCTL:INPUT_YEAR.
       ?x CCTL:year ?year_x.
       ?y CCTL:year ?year_y
     }
```

- *Facts related to a theory formulated in a given time range*. This third query retrieves all facts related to theories that have been formulated in a given time range. Such a query has been executed in Protege [33] on a draft of the ontology with the support of Snap SPARQL Query [39] in the time range 1980-2016. Results are reported in fig. 5. As shown, there are 31 events related to theories formulated in the target time

[7]Okjökull - Wikipedia, https://en.wikipedia.org/wiki/Okj"okull. Accessed: 21 October 2019.

[8]Iceland holds funeral for first glacier lost to climate change, https://www.sbs.com.au/news/iceland-holds-funeral-for-first-glacier-lost-to-climate-change. Accessed: 21 October 2019.

[9]SPARQL 1.1 Query Language - W3C Recommendation 21 March 2013, https://www.w3.org/TR/sparql11-query/. Accessed: 21 October 2019.

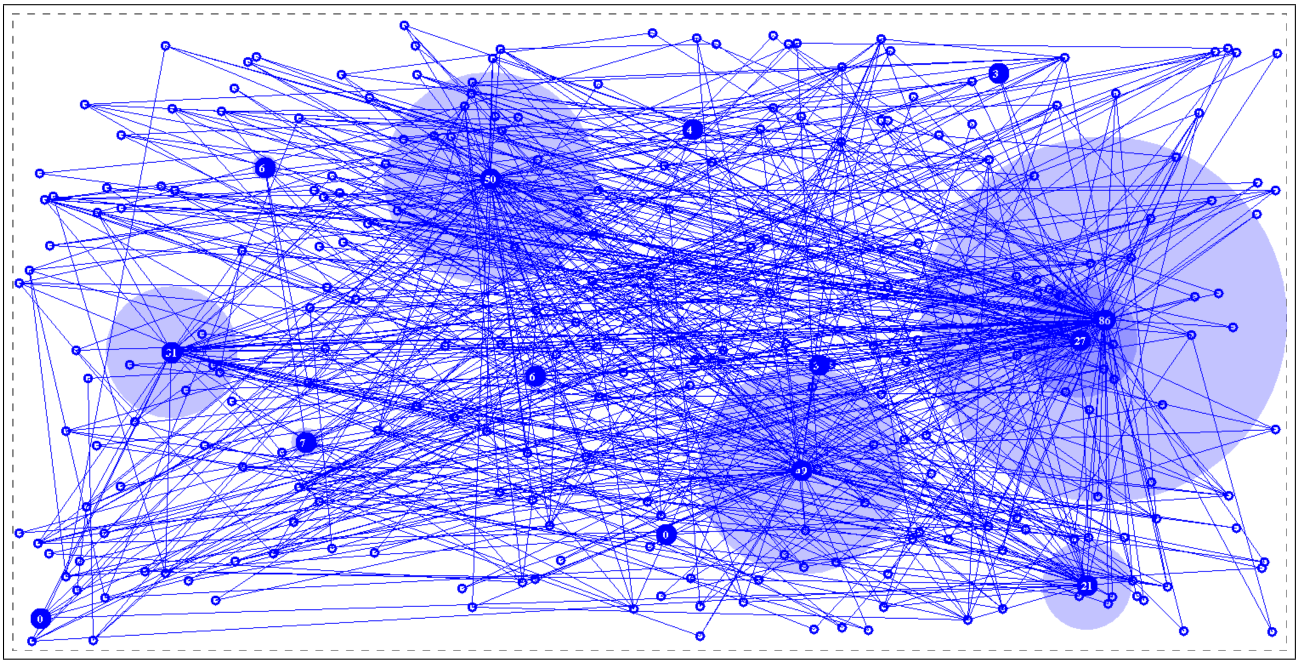


FIGURE 2. Representation of the timeline as a knowledge graph. It doesn't include the attributes associated with the different class instances.

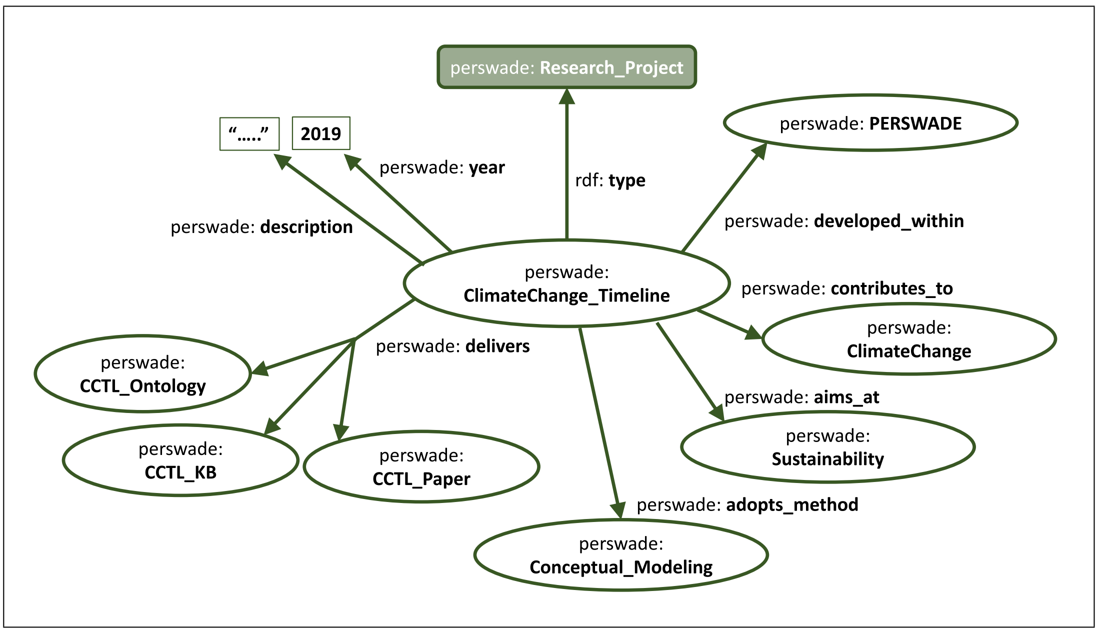


FIGURE 3. Project descriptor by using PERSWADE-CORE ontology.

range. This kind of query may become important in understanding the different phases of climate change story and the progressive consolidation of the different theories.

```
SELECT ?year_x ?x ?year_y ?y
WHERE {
     ?x CCTL:relatedTo ?y.
     ?x a CCTL:Theory.
     ?x CCTL:year_s ?year_x.
      FILTER(
          ?year_x >= INPUT_Start
          &&
          ?year_x <= INPUT_end
         )
       ?y CCTL:year_s ?year_y
}
```

V. APPLICATIONS

Because of the ontological approach adopted, our contribution aims to provide a generic semantic description of a

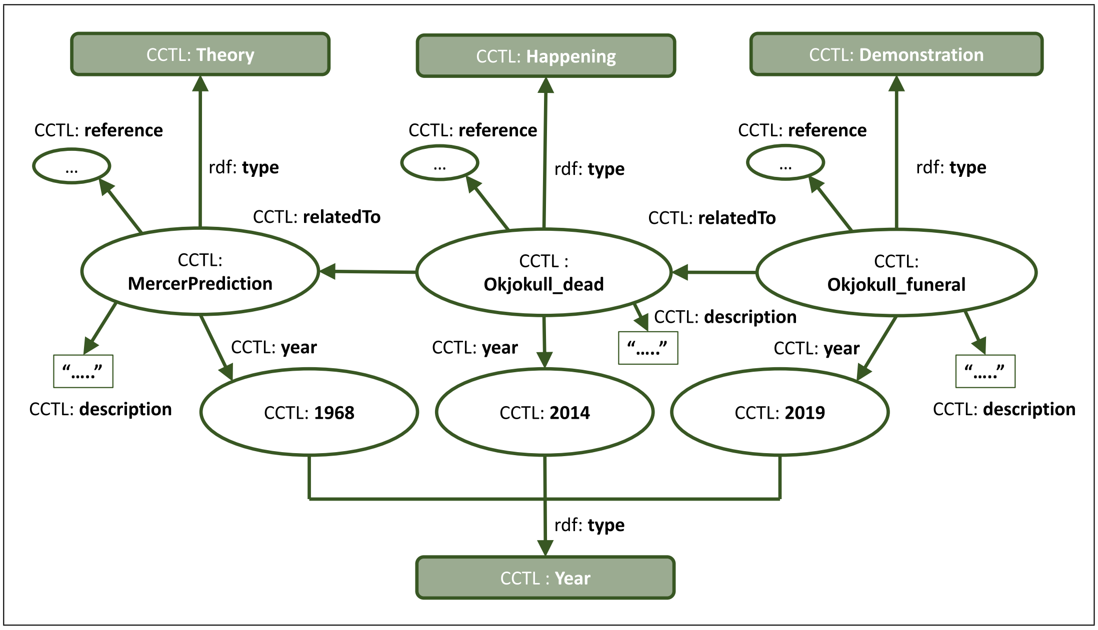
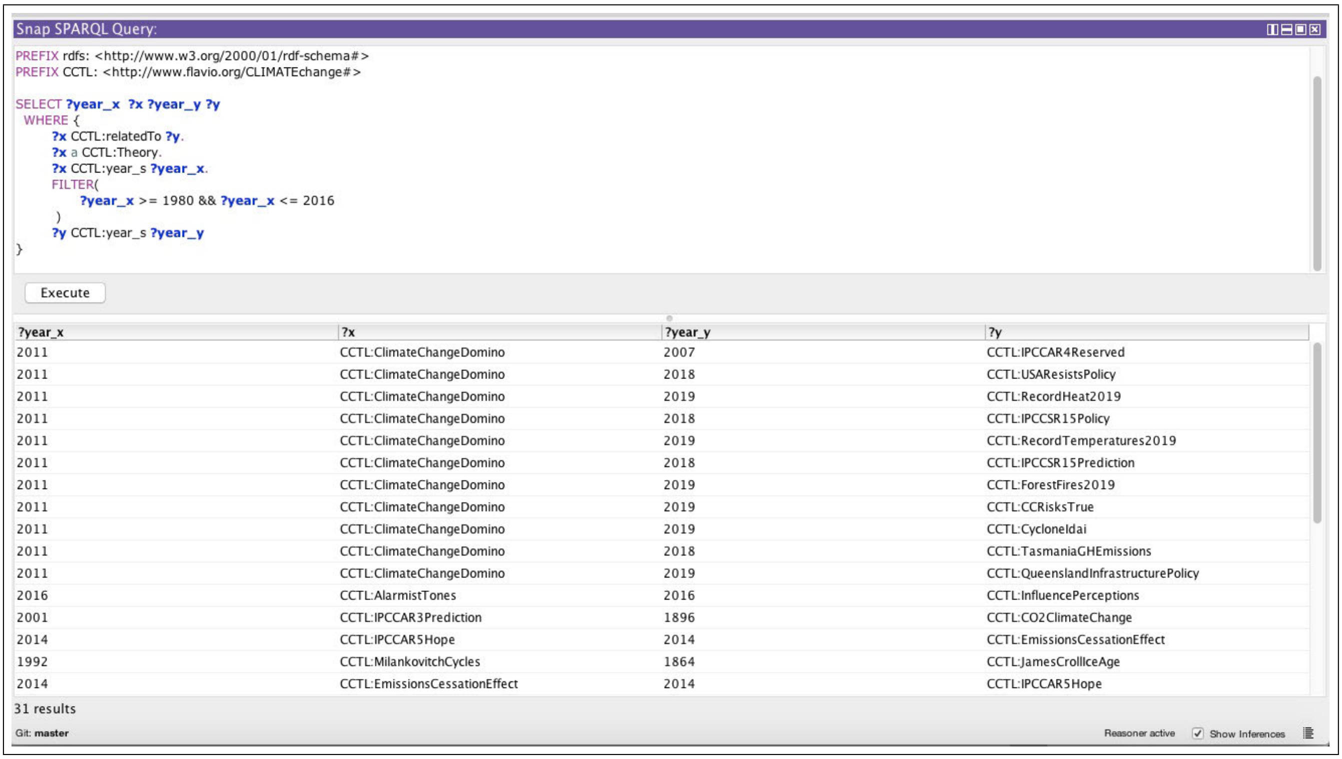


FIGURE 4. An example of formal specification involving 3 different correlated facts.



Snap SPARQL Query:

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX CCTL: <http://www.flavio.org/CLIMATEchange#>

SELECT ?year_x ?x ?year_y ?y
 WHERE {
      ?x CCTL:relatedTo ?y.
      ?x a CCTL:Theory.
      ?x CCTL:year_s ?year_x.
      FILTER(
          ?year_x >= 1980 && ?year_x <= 2016
       )
      ?y CCTL:year_s ?year_y
}
```

Execute

?year_x	?x	?year_y	?y
2011	CCTL:ClimateChangeDomino	2007	CCTL:IPCCAR4Reserved
2011	CCTL:ClimateChangeDomino	2018	CCTL:USAResistsPolicy
2011	CCTL:ClimateChangeDomino	2019	CCTL:RecordHeat2019
2011	CCTL:ClimateChangeDomino	2018	CCTL:IPCCSR15Policy
2011	CCTL:ClimateChangeDomino	2019	CCTL:RecordTemperatures2019
2011	CCTL:ClimateChangeDomino	2018	CCTL:IPCCSR15Prediction
2011	CCTL:ClimateChangeDomino	2019	CCTL:ForestFires2019
2011	CCTL:ClimateChangeDomino	2019	CCTL:CCRisksTrue
2011	CCTL:ClimateChangeDomino	2019	CCTL:CycloneIdai
2011	CCTL:ClimateChangeDomino	2018	CCTL:TasmaniaGHEmissions
2011	CCTL:ClimateChangeDomino	2019	CCTL:QueenslandInfrastructurePolicy
2016	CCTL:AlarmistTones	2016	CCTL:InfluencePerceptions
2001	CCTL:IPCCAR3Prediction	1896	CCTL:CO2ClimateChange
2014	CCTL:IPCCAR5Hope	2014	CCTL:EmissionsCessationEffect
1992	CCTL:MilankovitchCycles	1864	CCTL:JamesCrollIceAge
2014	CCTL:EmissionsCessationEffect	2014	CCTL:IPCCAR5Hope

31 results

Git: master   Reasoner active   Show Inferences

FIGURE 5. Facts related to a theory formulated between 1980 and 2016.

climate change timeline. Such a data infrastructure is agnostic with regards to applications and, in general terms, enables knowledge within the Semantic Web in which data may be inter-linked and semantically enriched via (semantic) interoperability.

In our opinion, the benefits of using such a data infrastructure could be especially effective, among others, in the context of the following applications:

- **Communication framework.** One of the most empathised issues around climate change is related to the communication between scientists and other stakeholders, especially decision making and citizens. Focusing on people perceptions, it is commonly accepted that, for a long time, climate change has not been considered like an actual and immediate threat. It is well known that history may help to not redo the same mistakes. Climate change may be making alarming headlines, however, its most critical chapters are yet to be written. The support of the systematic definition of climate change related facts can be useful to tell the story so far in context and to progressively enrich semantic specifications, including the relationships among the different happenings. Such kind of application may be useful to further raise awareness on the topic.

- **Specific-purpose knowledge base.** The same reasons that suggest a more effective and consistent communication among the different stakeholders point out the need for actual knowledge around climate change. Knowledge bases could contribute significantly in this sense as they are easily accessible though the Web, and, if properly designed and structured, may provide a valuable convergence point for informed discussion. We believe that the organization of the knowledge in a timeline can contribute to reach a wide audience focusing on the causality relationship between theories and happenings.
- **Information systems**. An ontological structure implemented upon Semantic Web technologies intrinsically provides some facilitations to information integration. Indeed, as the specifications are provided in a standard language, information can be accessed and integrated in any context, including systems whose purpose is not specifically related to climate change.
- **Knowledge specification and re-use within multidisciplinary environments.** Climate change related knowledge results from multi-disciplinary studies and it is intrinsically complex. This intrinsic interdisciplinary requires data, information and knowledge sharing among systems in different domains. The ontological approach fulfills requirements in terms of formal specification, interoperability and re-use.

We believe that a simple specification of events along the time dimension would not have provided a consistent support in the context of the above mentioned applications. On the contrary, a full ontological approach enables the progressive extension of the base taxonomy and the specification of a shared domain vocabulary resulting from the different disciplines and applications.

VI. CONCLUSION AND FUTURE WORK

We have provided an ontology (CCTL) to effectively describe climate change related events that can be related to each other, as well as they can be linked to external sources of information. CCTL is structured as a timeline which aims to describe the climate change story from multiple perspectives, including scientific, social, political and technological ones. We have created an instance of the ontology based on critical literature review and on the collection of factual information from relevant sources as an attempt the tell the story so far with a focus on most relevant theories, happenings, social and political initiatives.

Developed upon Semantic Web technology, such a knowledge space is enabled within the Semantic Web in which concepts are uniquely defined to enhance the interoperability model (Semantic Interoperability [40]). By definition, ontological structures are extensible and provide re-usable formal specifications for knowledge and data, which can be easily linked with each other and interchanged through the Web infrastructure.

Our approach allows the progressive definition of a knowledge base to tell the climate change story. The different key events, facts, theories and scientific evidences may be formally specified and automatically integrated as part of a unique knowledge base. Moreover, the specification of the relationships existing among the different climate change related facts provides further capabilities in terms of analysis supported by standard query languages. Semantic enrichments enable the specification of the context as linkage to external sources of information. Finally, by adopting an ontological format in a standard language, data may be easily re-used and interchanged across different systems.

Future work will aim to the application of CCTL in different contexts. CCTL is expected to evolve as per users' needs. For instance, a breakdown for the category *CCTL:Technology* could be provided according to some technology classification schema. The domain vocabulary is not object of this paper and will be obtained by analysing the references associated with the different events. Simple techniques based on keywords extraction will allow a systematic and fully automatic association of the key terminology with each event. The evolution of such domain vocabulary along the time is intrinsically supported because of the organization of the information along the time dimension. Nevertheless, the hierarchical organisation of such concepts will require a supervised approach involving experts from the different disciplines.

APPENDIX. ONTOLOGY POPULATION

We report in this appendix the current population of the ontology organised by category.

TABLE 3. Theories currently part of our knowledge base.

ID	Cat.	Year	Ref.	Related To	Description
GreenhouseEffect	Theory	1824	[41]	-	Joseph Fourier theorized and demonstrated the greenhouse effect.
JamesCrollIceAge	Theory	1864	[42]	-	James Croll theorized that new snow coverage of regions could lead to an ice age.
CO2ClimateChange	Theory, ScientificEvidence	1896	[43]	GreenhouseGasEmissions	Svante Arrhenius theorized that a small change in carbon dioxide levels could change the climate.
CO2ControlKnob	Theory, ScientificEvidence	1896	[43]	CO2ClimateChange, GreenhouseGasEmissions	Arrhenius established that CO2 is the principle control knob for climate change.
ChaoticClimate	Theory, ScientificEvidence	1897	[44]	CO2ControlKnob, GreenhouseGasEmissions	Thomas C. Chamberlin established the many factors that influence the carbon cycle.
WaterVapourGreenhouse	Theory, ScientificEvidence	1965	[45]	GreenhouseGasEmissions	Water vapour in the air locks in more heat in a combined effect.
CO2Doubling	Theory, ScientificEvidence	1967	[46]	CO2ControlKnob, GreenhouseGasEmissions	Doubling CO2 levels results in a 2°C increase in overall temperatures.
MercierPrediction	Theory, ScientificEvidence	1968	[38]	-	A rise in temperature may melt the WAIS, raising sea levels by 5 metres.
OceanCurrents	Theory, ScientificEvidence	1969	[47]	WaterVapourGreenhouse	A model that accounts for ocean currents and their influence on atmospheric circulations.
InterglacialPeriods	Theory, ScientificEvidence	1982	[48]	EmilianiSediments	Interglacial periods last 10,000 years.
MilankovitchCycles	Theory, ScientificEvidence	1992	[49]	JamesCrollIceAge	Shifts in the Earth's axis would set off periods of warming and cooling and trigger ice ages.
IPCCAR3Prediction	Theory	2001	[50]	CO2ClimateChange	A prediction of 1.4°C to 5.8°C increase in temperatures by the end of the 21st century due to the unprecedented spike in carbon emissions.
ICTPrediction2020	Theory	2007	[51]	-	It was projected that by 2020 the greenhouse footprint of the global ICT industry would be at 3.06% - 3.6% of the aggregate global greenhouse emissions recorded in 2007.
EmissionsCessationEffect	Theory	2014	[52] [53]	-	Even if emissions were to cease completely, rise in temperatures and sea levels would be consistent at least until 2100.
IPCCAR5Hope	Theory	2014	[52] [53]	EmissionsCessationEffect	Still possible to keep below 2°C of pre-industrial temperatures if policies are adapted to reduce and finally cease greenhouse emissions by the end of the 21st century.
AlarmistTones	Theory	2016	[54]	InfluencePerceptions	Alarmist tones about climate change may not only be futile, but also counter-productive.
InfluencePerceptions	Theory	2016	[54]	PublicKnowledgeTraction	A number of factors, including global vs. local warming, global warming vs. climate change, and numeric vs. non-numeric communication, were found to mold perceptions on climate change.
ICTPrediction2040	Theory	2018	[51]	ICTPrediction2020	It is forecasted that by 2040, if the ICT industry goes unchecked it could account for as much as 14% of the total global greenhouse emissions recorded in 2016 by an exponential fit.
IPCCSR15Prediction	Theory	2018	[55]	ClimateChangeDomino	IPCC SR15 projected global warming to be at 1.5°C by 2040 at current rates of emission.
DataCentreEmissions	Theory	2018	[51]	ICTPrediction2020	It is projected that by 2020, 45% of ICT greenhouse footprint will be due to the energy used in data centers
SpeciesExtinction	Theory	2019	[56]	IPCCSR15Prediction	The rise in temperature is a threat to all lives, with one million species at risk.

TABLE 4. Happenings currently part of our knowledge base [PART 1].

ID	Cat.	Year	Ref.	Related To	Description
Weather&TemperatureDataCollection	Happening	1879	[57]	-	Collection and standardization of weather and temperature data by International Meteorological Organization (IMO) began.
GlobalTemperatureRecords	Happening	1880	[58]	Weather&TemperatureDataCollection	Global temperature records began being collected by World Meteorological Organization (WMO).
ClimateUnpredictable	Happening	1961	[59]	CO2ClimateChange, CO2ControlKnob, ChaoticClimate	Scepticism regarding trying to predict an unpredictable natural phenomenon.
EarthDay	Happening, SocialAwareness	1970	[60]	-	The first Earth Day celebrated.
UNEPEstablished	Happening, PoliticalInitiative	1972	[61]	-	The United Nations Environment Programme (UNEP) was established.
ChernobylNuclearDisaster	Happening, SocialAwareness	1986	[62]	-	Nuclear Reactor disaster at Chernobyl has negative impact on public support of nuclear energy.
MathematicalModelsCriticized	Happening	1987	[63]	-	Mathematical models were criticized for only allowing smooth temperature transitions.
JamesHansenTestimonial	Happening, SocialAwareness	1988	[20]	-	Jame Hansen's testimonial changed the newspaper tone about climate change from one of scientific significance to one of controversy.
IPCCEstablished	Happening, PoliticalInitiative	1988	[64]	GlobalTemperatureRising	Intergovernmental Panel on Climate Change (IPCC) was established.
IPCCFirstIssue	Happening	1990	[65]	IPCCEstablished	First issue of IPCC was published.
KyotoProtocolEstablished	Happening, PoliticalInitiative	1997	[66]	-	The Kyoto Protocol was established in an attempt to bind developed economies to an emissions reduction plan.
ChinaWorstPolluter	Happening	2000-2009	[67]	KyotoProtocolEstablished	China became the worst carbon emitter in the 2000s.
MilankovitchCycles	Happening, ScientificEvidence	2000-2009	[49]	IPCCFirstIssue	Prolonged droughts affect developing economies.
Greenland&AntarcticIceMelting	Happening	2001-2009	[68]	MercerPrediction	Data captured via satellite showed that ice in Greenland and the Antarctic were melting at alarming rates.
GreenlandIceMelting	Happening	2001-2006	[69]	-	Greenland ice melting at alarming rates.
PineIslandBayIceMelting	Happening	2001-2006	[70]	MercerPrediction	PPine Island Bay ice melted by 5kms in 5 years.
EuropeanHeatWave	Happening	2003	[71]	IPCCFirstIssue	Rise in temperature caused heat waves that affected the rich nations of Europe.
DeathCountEuropeanHeatWave	Happening	2003	[72]	EuropeanHeatWave	70,000 lives lost in the European heat wave.
IPCCAR4Reserved	Happening	2007	[73]	-	IPCC AR4 reserved due to political influences, with predictions of freak storms and record temperatures.
30GTCarbonEmissions	Happening	2010	[74]	-	Despite the 2009 economic recession, carbon emissions had risen by 1.6GT from 29GT, and now emissions were in the 30s.
DurbanClimateChangeAgreement	Policy, Happening	2011	[75]	KyotoProtocolEstablished	The Durban Climate Change Conference 2011 hosted by UNFCC got 190 countries, including China, the US and India, to come to an agreement for a target to keep global temperature under the 2°C mark.
ClimateCommisionReport	Happening, SocialAwareness	2011	[76]	-	Climate Commission of Australia published its first report outlining the dangers of continued anthropogenic greenhouse emissions.

TABLE 5. **Happenings currently part of our knowledge base [PART 2].**

ID	Cat.	Year	Ref.	Related To	Description
ClimateChangeDomino	Happening, Policy	2011	[77]	IPCCAR4Reserved, USAResistsPolicy	IEA issued warning to stay within 2°C of permissible change or face the uncontrollable domino effect.
ArcticIceLossVisualization	Happening	2012	[78]	Greenland&AntarcticIceMelting	Arctic ice reduced to 4 million km2 in just 9 months from historical average of 7 million km2.
NSIDCArcticIce2012	Happening	2012	[79]	ArcticIceLossVisualization, Greenland&AntarcticIceMelting	Arctic ice record minimum at 3.41 million km2.
Emissions&Storms2012	Happening	2012	[80]	IPCCAR4Reserved	Record carbon emissions and unusual storms, including a hurricane in the Caribbean and a typhoon in the Philippines.
TyphoonHaiyan	Happening	2013	[81]	IPCCAR4Reserved	Typhoon Haiyan induced by warmer ocean temperatures, one of the strongest on record.
2013AustraliaRecordTemp	Happening	2013	[82]	IPCCAR4Reserved	Australia experienced its hottest month on record in January 2013 with an 8 day average temperature of 39°C.
2013NewZealandDrought	Happening	2013	[83]	IPCCAR4Reserved	New Zealand experienced its worst drought since the 1980s.
2013USATornado	Happening	2013	[84]	IPCCAR4Reserved	US experienced its widest tornado on record in May 2013 at a width of 2.6 miles.
2013FreakStorms&Temps	Happening	2013	[84]	IPCCAR4Reserved	A series of freak storms, record breaking temperatures, rainfall, and dryness experienced across continents.
IPCCAR5	Happening, ScientificEvidence	2014	[52]	IPCCAR4Reserved	IPCC AR5 confirmed increased levels of greenhouse gases in the atmosphere, melting ice, rising sea levels, loss of lives, human and animal habitats, crops and livelihoods, and severe record breaking weather and temperature patterns.
Okjokull_dead	Happening	2014	Wikipedia[7]	MercerPrediction	Ok glacier was declared dead.
ParisAgreement	PoliticalInitiative, Happening	2015	[85]	DurbanClimateChangeAgreement, KyotoProtocolEstablished	The Paris Agreement brought all 197 countries (Parties) of the UNFCCC under a binding agreement to actively fight climate change.
RenewableEnergy	Policy, Happening	2016	[86]	ParisAgreement	Parties to the UNFCCC started moving towards renewable energy sources by making it more cost-effective in comparison to fossil fuel.
RecordHeat2016	Happening	2016	[87]	IPCCAR5	January-June 2016 were each month successively hotter than any on record since 1880.
ArcticIce2016	Happening	2016	[87]	IPCCAR5, NSIDCArcticIce2012, ArcticIceLossVisualization, Greenland&AntarcticIceMelting	Least amount of sea ice observed in the Arctic since satellite records started in 1979.
TrumpAdministration	PoliticalInitiative, Happening	2017	[88]	DurbanClimateChangeAgreement, KyotoProtocolEstablished, ParisAgreement	President Trump's administration took a step back from USA's prior agreements, a serious blow to climate change efforts globally.
USEnergyCompanies	Happening, Demonstration	2017	[89]	TrumpAdministration, ParisAgreement	US energy companies, such as ExxonMobil, Cloud Peak Energy and Cheniere Energy urged the Trump Administration to stick to the Paris Agreement.
GretaThunbergDebut	Happening, Demonstration	2018	[90]	-	Greta Thunberg's solitary school strike outside the Swedish Parliament in August 2018.
TasmaniaGHEmissions	Happening, ScientificEvidence	2018	[91]	ClimateChangeDomino	Total greenhouse gases in Tasmania were at a staggering 500ppm carbon dioxide equal on record in the last 0.8-2 million years.
CycloneIdai	Happening, ScientificEvidence	2019	[92]	IPCCSR15Prediction, ClimateChangeDomino	Freak storms are becoming the norm, disrupting livelihoods and resulting in deaths by the hundreds.
CCRisksTrue	Happening	2019	[93]	IPCCSR15Prediction, ClimateChangeDomino	The icecaps are melting, causing a rise in sea levels, threatening civilizations close to the shore, a majority of who already fall in the impoverished group, and causing massive displacements of people.
Deforestation	Happening	2019	[94]	-	Deforestation ranked as the No.3 biggest carbon emitter by the Global Forest Watch after China and US.
AmazonWildfires	Happening, Policy	2019	[95]	ParisAgreement	The mass uncontrollable wildfires of the Amazons are a major setback to the emission targets set by the Paris Agreement.
QueenslandInfrastructurePolicy	Happening, Policy	2019	[96]	IPCCSR15Prediction, ClimateChangeDomino	Unprecedented fires raging in Queensland, Australia, has led to discourse of building infrastructure with future climate change risks in mind.

TABLE 6. Happenings currently part of our knowledge base [PART 3].

ID	Cat.	Year	Ref.	Related To	Description
GretaPoliticalAttack	SocialAwareness, Happening	2019	[97]	GretaThunbergGlobal	Greta Thunberg politically attacked to dissuade public support.
GretaThunbergGlobal	Happening, Demonstration	2019	[98]	GretaThunbergDebut	On 15 March 2019, Greta Thunberg joined globally by about 1.6 million students to school strike to protest government inaction.
GretaThunbergRecognition	Happening, SocialAwareness	2019	[90]	GretaThunbergGlobal	GretaThunberg awarded the German Golden Camera as an iconic youth leader, and nominated for the Prix Liberte of France and the prestigious Nobel Peace Prize.
GretaThunbergLifestyle	Happening, SocialAwareness	2019	[99]	GretaThunbergDebut, GretaThunbergGlobal, GretaThunbergRecognition	Greta Thunberg traveled in a carbon neutral boat for 15 days to attend the UN Climate Action Summit in New York.
RecordTemperatures2019	Happening	2019	[100]	IPCCSR15Prediction, ClimateChangeDomino	400 record temperatures set during May-August 2019.
RecordHeat2019	Happening	2019	[101]	IPCCSR15Prediction, ClimateChangeDomino, RecordTemperatures2019	July 2019 has been the hottest month ever since records began.
ForestFires2019	Happening	2019	[102]	IPCCSR15Prediction, ClimateChangeDomino, RecordTemperatures2019	An estimated carbon emission of 100 million tons due to intense forest fires in the Arctic regions of Alaska, Canada and Siberia alone.
GreenlandIceRecord	Happening	2019	[103]	IPCCAR5, NSIDCArcticIce2012, ArcticIceLossVisualization, ArcticIce2016	Greenland's ice sheet melted a record 12.5 bn tons of ice in just one day on 1 August 2019.

TABLE 7. Facts related to social awareness currently part of our knowledge base.

ID	Category	Year	Reference	Related To	Description
EarthDay	Happening, SocialAwareness	1970	[60]	-	The first Earth Day celebrated.
PoorPublicAwareness	SocialAwareness	1980-1984	[21]	-	In the early 1980s, only about 30% of respondents were aware of climate change.
ChernobylNuclearDisaster	Happening, SocialAwareness	1986	[62]	-	Nuclear Reactor disaster at Chernobyl has negative impact on public support of nuclear energy.
PublicKnowledgeTraction	SocialAwareness	1986-1989	[21]	PoorPublicAwareness, ChernobylNuclearDisaster	Public knowledge gained traction around the late 1980s where up to 70% of respondents were aware of climate change.
CelebrityEndorsements	SocialAwareness	1987-2006	[16]	PublicKnowledgeTraction	Celebrities may have helped garner a larger audience, but their fans may endorse the climate change cause for the wrong reasons.
JamesHansenTestimonial	Happening, SocialAwareness	1988	[20]	-	Jame Hansen's testimonial changed the newspaper tone about climate change from one of scientific significance to one of controversy.
PoorPublicKnowledge	SocialAwareness	1990	[21]	PublicKnowledgeTraction, JamesHansenTestimonial	90% awareness of climate change, however, poor understanding of its reasons.
USClimateDebate	SocialAwareness	1998-2001	[20]	JamesHansenTestimonial	US news coverage of climate change was more of a debate about its reality.
ClimateChangeVotes	SocialAwareness	1999	[104]	PoorPublicKnowledge	A majority of the public were influenced by personal convenience considerations when voting on climate change policies.
EuropeClimateDebate	SocialAwareness	2000-2006	[20]	PoorPublicKnowledge	European news coverage of climate change was mainly about freak weathers and wildlife extinction.
CCNewsCoverage	SocialAwareness	2004-2011	[105]	PoorPublicAwareness	Climate change news coverage was higher in developed economies rather than developing economies.
ClimateCommisionReport	Happening, SocialAwareness	2011	[76]	-	Climate Commission of Australia published its first report outlining the dangers of continued anthropogenic greenhouse emissions.
ClimategateScandal	SocialAwareness	2012	[106]	USClimateDebate	While there has been rising skepticism in the US on the reality of climate change following the climategate scandal, scientists were still believed to be the best source for factual information.
GovernmentSued	SocialAwareness	2015	[107]	PublicKnowledgeTraction	Dutch environmental group sued the government with the support of 886 citizens over their failure to cut greenhouse emissions, and won.
CCReality	SocialAwareness	2015	[108]	PoorPublicKnowledge	A significant portion of the global population are unaware of anthropogenic climate change, and another portion donâĂŹt believe in its reality.
GretaThunbergDebut	Happening, Demonstration	2018	[90]	-	Greta Thunberg's solitary school strike outside the Swedish Parliament in August 2018.
GretaPoliticalAttack	SocialAwareness, Happening	2019	[97]	GretaThunbergGlobal	Greta Thunberg politically attacked to dissuade public support.
GretaThunbergGlobal	Happening, Demonstration	2019	[98]	GretaThunbergDebut	On 15 March 2019, Greta Thunberg joined globally by about 1.6 million students to school strike to protest government inaction.
GretaThunbergRecognition	Happening, SocialAwareness	2019	[90]	GretaThunbergGlobal	GretaThunberg awarded the German Golden Camera as an iconic youth leader, and nominated for the Prix Liberte of France and the prestigious Nobel Peace Prize.
GretaThunbergLifestyle	Happening, SocialAwareness	2019	[99]	GretaThunbergDebut, GretaThunbergGlobal, GretaThunbergRecognition	Greta Thunberg traveled in a carbon neutral boat for 15 days to attend the UN Climate Action Summit in New York.
Okjokull_funeral	Demonstration	2019	SBS News[8]	Okjokull_dead	Activists celebrated the funeral of Ok glacier.

TABLE 8. Scientific evidences currently part of our knowledge base [PART 1].

ID	Cat.	Year	Ref.	Related To	Description
GreenhouseEffect-Confirmed	ScientificEvidence	1859	[109]	GreenhouseEffect	John Tyndall's experiments confirmed that atmospheric gases can trap heat.
GreenhouseGasEmissions	ScientificEvidence	1859	[109]	GreenhouseEffectConfirmed	Greenhouse gases linked to the industrial use of fossil fuels.
JamesCrollIceAge	Scientific Evidence	1864	[42]	-	James Croll theorized that new snow coverage of regions could lead to an ice age.
FirstEvidenceGlobal-Warming	Scientific Evidence	1880-1935	[110]	GlobalTemperatureRising	Guy Stewart Callendar demonstrated that global temperatures had risen by 0.3°C.
CO2ClimateChange	Theory, ScientificEvidence	1896	[43]	GreenhouseGasEmissions	Svante Arrhenius theorized that a small change in carbon dioxide levels could change the climate.
CO2ControlKnob	Theory, ScientificEvidence	1896	[43]	CO2ClimateChange, GreenhouseGasEmissions	Arrhenius established that CO2 is the principle control knob for climate change.
ChaoticClimate	Theory, ScientificEvidence	1897	[44]	CO2ControlKnob, GreenhouseGasEmissions	Thomas C. Chamberlin established the many factors that influence the carbon cycle.
AnthropogenicObservedWarming	ScientificEvidence	1950-2010	[111]	ModernGlobalWarming	93-123% of observed warming since 1950 is anthropogenic.
WaterVapourGreenhouse	Theory, ScientificEvidence	1965	[45]	GreenhouseGasEmissions	Water vapour in the air locks in more heat in a combined effect.
CO2Doubling	Theory, ScientificEvidence	1967	[46]	CO2ControlKnob, GreenhouseGasEmissions	Doubling CO2 levels results in a 2°C increase in overall temperatures.
MercierPrediction	Theory, ScientificEvidence	1968	[38]	-	A rise in temperature may melt the WAIS, raising sea levels by 5 metres.
OceanCurrents	Theory, ScientificEvidence	1969	[47]	WaterVapourGreenhouse	A model that accounts for ocean currents and their influence on atmospheric circulations.
JohnstonNitrateEmissions	ScientificEvidence	1971	[112]	GreenhouseGasEmissions	Nitrate molecules emitted from planes negatively impact the ozone layer.
MethaneEmissions	ScientificEvidence	1974	[113]	GreenhouseGasEmissions	Methane emissions are a much bigger contributor to greenhouse emissions than minerals.
EmilianiSediments	ScientificEvidence	1975	[114]	MercerPrediction	Cesare Emiliani obtained deep-sea sediments that evidenced rapid rises in sea level by the meters.
TysonNitrateEmissions	ScientificEvidence	1978	[115]	JohnstonNitrateEmissions	Nitrate molecules emitted from planes negatively impact the ozone layer.
GlobalTemperatureRising	ScientificEvidence	1980	[116]	GlobalTemperatureRecords	Scientists began to notice that global temperatures had been rising over the past century.
DansgaardIceEvidence	ScientificEvidence	1982	[48]	InterglacialPeriods	2kms of ice recovered evidenced huge fluctuations in temperatures and carbon levels.
InterglacialPeriods	Theory, ScientificEvidence	1982	[48]	EmilianiSediments	Interglacial periods last 10,000 years.
MethaneLevelsRising	ScientificEvidence	1988	[117]	MethaneEmissions	Methane levels had been rising by 1% each year.

TABLE 9. Scientific evidences currently part of our knowledge base [PART 2].

ID	Cat.	Year	Ref.	Related To	Description
IceAge-Warming	ScientificEvidence	1990-1999	[118]	DansgaardIceEvidence, InterglacialPeriods	Warming followed by the last ice age began centuries before any change in CO2 levels in the atmosphere.
Milankovitch-Cycles	Happening, ScientificEvidence	2000-2009	[49]	IPCCFirstIssue	Prolonged droughts affect developing economies.
DevelopingEconomies-Droughts	Happening, ScientificEvidence	2000-2009	[119]	JamesCrollIceAge	Shifts in the Earth's axis would set off periods of warming and cooling and trigger ice ages.
IPCCAR5	Happening, ScientificEvidence	2014	[52]	IPCCAR4Reserved	IPCC AR5 confirmed increased levels of greenhouse gases in the atmosphere, melting ice, rising sea levels, loss of lives, human and animal habitats, crops and livelihoods, and severe record breaking weather and temperature patterns.
Modern-Global-Warming	ScientificEvidence	2016	[120]	GlobalTemperatureRising, AnthropogenicObservedWarming	Modern global warming coincides with the start of the First Industrial Revolution, indicating that modern global warming is human induced.
19thCenturyGlobal-Warming	ScientificEvidence	2016	[121]	ModernGlobalWarming, GlobalTemperatureRising	Modern global warming started in the early 19th century as evidenced by ice bergs, ancient trees and coral reefs.
TasmaniaGHEmissions	Happening, ScientificEvidence	2018	[91]	ClimateChange-Domino	Total greenhouse gases in Tasmania were at a staggering 500ppm carbon dioxide equal on record in the last 0.8-2 million years.
CycloneIdai	Happening, ScientificEvidence	2019	[92]	IPCCSR15Prediction, ClimateChange-Domino	Freak storms are becoming the norm, disrupting livelihoods and resulting in deaths by the hundreds.

TABLE 10. Political initiatives currently part of our knowledge base.

ID	Cat.	Year	Ref.	Related To	Description
UNEPEstablished	Happening, PoliticalInitiative	1972	[61]	-	The United Nations Environment Programme (UNEP) was established.
IPCCEstablished	Happening, PoliticalInitiative	1988	[65]	GlobalTemperatureRising	Intergovernmental Panel on Climate Change (IPCC) was established.
KyotoProtocolEstablished	Happening, PoliticalInitiative	1997	[66]	-	The Kyoto Protocol was established in an attempt to bind developed economies to an emissions reduction plan.
DurbanClimateChangeAgreement	Policy, Happening	2011	[75]	KyotoProtocolEstablished	The Durban Climate Change Conference 2011 hosted by UNFCC got 190 countries, including China, the US and India, to come to an agreement for a target to keep global temperature under the 2Âř C mark.
ClimateChangeDomino	Happening, Policy	2011	[77]	IPCCAR4Reserved, USAResistsPolicy	IEA issued warning to stay within 2°C of permissible change or face the uncontrollable domino effect.
ParisAgreement	PoliticalInitiative, Happening	2015	[85]	DurbanClimateChangeAgreement, KyotoProtocolEstablished	The Paris Agreement brought all 197 countries (Parties) of the UNFCCC under a binding agreement to actively fight climate change.
RenewableEnergy	Policy, Happening	2016	[86]	ParisAgreement	Parties to the UNFCCC started moving towards renewable energy sources by making it more cost-effective in comparison to fossil fuel.
TrumpAdministration	PoliticalInitiative, Happening	2017	[88]	DurbanClimateChangeAgreement, KyotoProtocolEstablished, ParisAgreement	President Trump's administration took a step back from USA's prior agreements, a serious blow to climate change efforts globally.
USEnergyCompanies	Happening, Demonstration	2017	[89]	TrumpAdministration, ParisAgreement	US energy companies, such as ExxonMobil, Cloud Peak Energy and Cheniere Energy urged the Trump Administration to stick to the Paris Agreement.
USAResistsPolicy	PoliticalInitiative	2018	[122]	TrumpAdministration, ParisAgreement, ClimateChangeDomino	USA did not believe that it would be affected by climate change being a rich nation.
IPCCSR15Policy	Policy, Theory	2018	[55]	ClimateChangeDomino	If radical changes are made by 2020 using technology, infrastructure and policies as recommended by the IPCC, net zero carbon emissions could be reached by 2055 or 2040.
AmazonWildfires	Happening, Policy	2019	[95]	ParisAgreement	The mass uncontrollable wildfires of the Amazons are a major setback to the emission targets set by the Paris Agreement.
QueenslandInfrastructurePolicy	Happening, Policy	2019	[96]	IPCCSR15Prediction, ClimateChangeDomino	Unprecedented fires raging in Queensland, Australia, has led to discourse of building infrastructure with future climate change risks in mind.

TABLE 11. Facts related to technology currently part of our knowledge base.

ID	Category	Year	Reference	Related To	Description
ICTCarbonSlowed	Technology	2000-2015	[123]	ICTPrediction2020	The carbon footprint for the ICT industry has slowed down over the period 2000-2015 due to resource decoupling, a trend projected to continue in 2020.
ICTEnergyConsumption	Technology	2000-2015	[123]	ICTCarbonSlowed	Energy consumption has increased only slightly, attributable to ICT users growing over ten times, while energy consumption/user has decreased by about 67%.
ICTPrediction2020	Technology	2018	[51]	-	It was projected that by 2020 the greenhouse footprint of the global ICT industry would be at 3.06% - 3.6% of the aggregate global greenhouse emissions recorded in 2007.
ICTEmissions	Technology	2008	[124]	ICTPrediction2020	ICT related emissions are comparable to emissions caused by the air travel industry.
ICTPrediction2040	Technology	2018	[51]	ICTPrediction2020	It is forecasted that by 2040, if the ICT industry goes unchecked it could account for as much as 14% of the total global greenhouse emissions recorded in 2016 by an exponential fit.
DataCentreEmissions	Technology	2018	[51]	ICTPrediction2020	It is projected that by 2020, 45% of ICT greenhouse footprint will be due to the energy used in data centers.

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