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# Sustainability in Modelling of Cyber-Physical Systems: A Systematic Literature Review - Intermediate Technical Report

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**Ankica Barišić, Jacome Cunha**

## **Sustainability in Modelling of Cyber-Physical Systems: A Systematic Literature Review**

Intermediate Technical Report



FACULDADE DE  
CIÊNCIAS E TECNOLOGIA  
UNIVERSIDADE NOVA DE LISBOA

**April, 2017**



## ABSTRACT

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**Background:** Supporting sustainability is becoming an active area of research. We want to contribute the first Systematic Literature Review (SLR) in this field over the Cyber-Physical Systems (CPS) to aid researchers who are motivated to contribute to that topic by providing a body of knowledge as starting point.

**Aim:** We aim to provide an overview of different approaches of sustainability which can be incorporated into modeling of CPS with regard to research activity, investigated topics, identified limitations, proposed approaches, used methods, available studies, and considered domains.

**Method:** The applied method is a SLR in four reliable and commonly-used databases according to the protocol by Kitchenham et al. [4]. We assessed the results of each database in period of 2011 to 2017.

**Results:** We identify the 680 candidates which are to be reviewed.

**Keywords:** Cyber-Physical systems, Sustainability, Systematic Literature Review,

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## SLR DEFINITION

Systematic Literature Review (SLR) is a research method to obtain, evaluate, and interpret information related to a research question. A SLR provides an objective reliable, rigorous, and methodological manner to conduct some study. In this report a SLR of sustainability in modelling of Cyber-Physical Systems (CPS) is conducted. This research aim requires accumulating a body of knowledge for various reasons: justifying the basis for future research, learning as much as possible from other domains related to the topic, and providing a basis for other researchers as well as students who consider learning about and contributing to this area.

### 1.1 SLR Objectives

The research objective of this SLR is to Identify and analyse modelling approaches for CPS regarding to sustainability concern. We expect to give an overview of the current state of the art in supporting sustainability during modeling of CPS. With this objective, we systematically investigate the research literature of modelling of CPS in the period between 2011-2017. The quest is to identify models, and implementations in a model-driven formal way that lends itself to a more systematic change tracking, self-healing, dynamic tuning and well-use of resources of CPSs. Next is to summarize the State-of-the-art research trends, as well as to categorize proposed approaches, techniques, tools and methods for assessing and improving a sustainability of CPS.

The industry is currently seeing a rapid development of cyber-physical system (CPS) products. The systems that are developed have increasing demands of sustainability, dependability and usability. Moreover, lead time and cost efficiency continue to be essential for industry competitiveness. Extensive use of modeling and simulation throughout the value chain and system life-cycle is one of the most important ways to effectively target

these challenges. Large-scale and increasingly software-defined systems in power and factory automation are very long-lived. Longevity requires sustainability - economically, environmentally and in terms of usability. Sustainability therefore requires continuous change. This SLR is meant to indentify models, and implementations in a model-driven formal way that lends itself to a more systematic change tracking, self-healing, dinamic tuning and well-use of resources of CPSs.

## 1.2 Research Questions

A main research questions are the following:

- **RQ1** Which modeling approaches exist for building CPS?
- **RQ1.1** Among existing approaches are there ones which concern sustainability?
- **RQ2** Which approaches for addressing sustainability exist?
- **RQ2.1** Are there ones which can be applied to CPS?
- **RQ3** Which application domains have been considered?
- **RQ4** Which modelling approaches for addressing sustainability of CPS exist?

Further we define PICOC analysis which specified in detail our search for evidence:

*Population:* The population is composed by studies in which we found reports about works for modeling CPS and/or approaches for sustainability, preferably which can be applied in CPS context. No specific industry, system or application domain were considered. works for modeling CPS.

*Intervention:* The review searches for reports of methodologies for sustainability assessments, namely focusing on 2 important factors; Reported for CPS; Reported for software products and applicable to CPS. We also search for the methodology/tool/technology/procedure that support the modelling of CPS while taking in consideration a sustainability concerns (e.g. energy efficiency, resilience, accessibility, etc.).

*Comparison:* Not applicable

*Outcomes:* Outcomes should point to techniques, methods and metrics that can be used to address the sustainability of CPS during their modeling/design phase.

*Context:* All practitioners: Academy and Industry

## 1.3 SLR Process

In the context of this SLR, we planned our SLR process as suggested by Kitchenham (see Figure 1.1. in the planning phase the review protocol was developed, and validated during Protocol Review Session by receiving feedback in a closed presentation workshop, which was followed by survey. Following the initial step of definition of the research

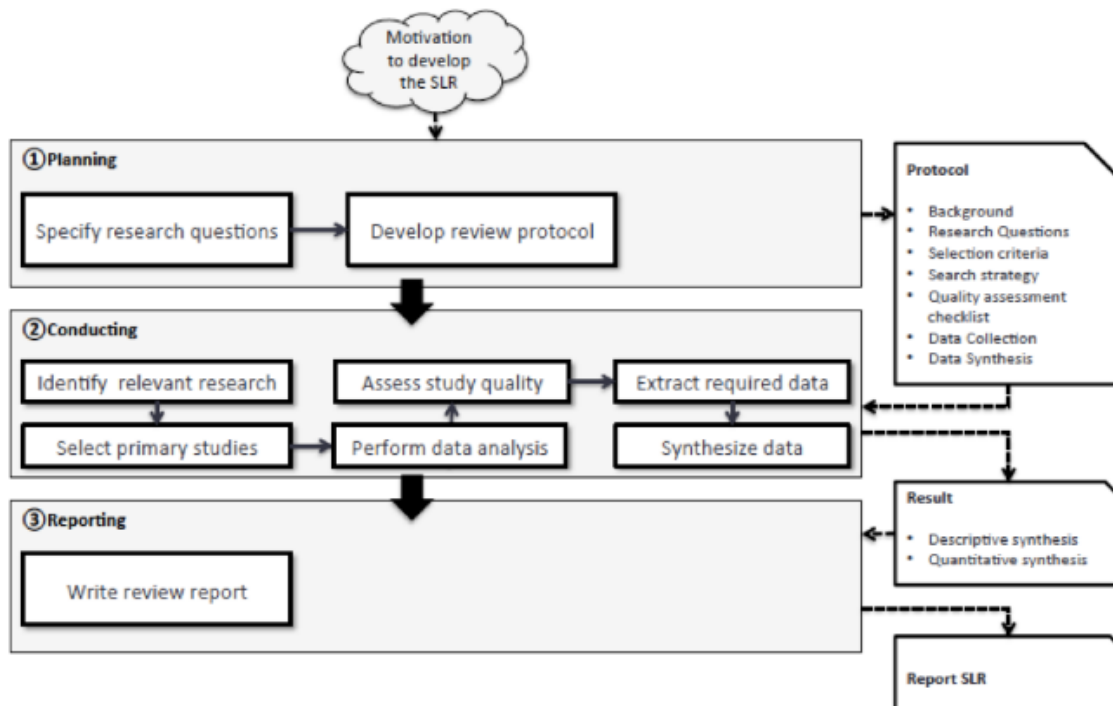


Figure 1.1: Review Process Overview taken from [3]

question, an initial list of studies is created during the identify relevant research step. The list will be used as a starting point in the primary study selection step. Each article will be examined to select studies which answer the original research question. This required the definition of selection criteria that will be the objective guidance in selecting primary studies. We record all inclusion and exclusion rules to determine if one study can be a candidate for primary study. Primary studies are the output of the SLR method and the input for further analysis and discussion.

The activities and responsibilities for this project are defined in Table 1.1. We have two principal researchers (Ankica Barisic and Jacome Cunha), NOVA-LINCS research group as supporting researchers, and one external reviewer (Miguel Goulao).

Table 1.1: Planned SLR activities

<b>Activities</b>	<b>Responsible</b>	<b>Status</b>
Develop protocol	<i>Ankica Barisic</i>	done
Define search string	<i>Ankica Barisic</i>	done
Define classification scheme	<i>Ankica Barisic</i>	done
Define data extraction form	<i>Ankica Barisic</i>	done
Internal review of protocol	<i>Jacome Cunha</i>	done
External review of protocol	<i>NOVA-LINCS research group</i>	done
Prepare review questionnaire	<i>Ankica Barisic</i>	done
Revise protocol	<i>Ankica Barisic</i>	done
Identify primary research	<i>Ankica Barisic</i>	done
Create Intermediate technical report	<i>Ankica Barisic</i>	ongoing
Internal Review of technical report	<i>Jacome Cunha</i>	ongoing
External Review technical report	<i>Ana Moreira</i>	1.8.2017
Retrieve primary research	<i>Ankica Barisic, Jacome Cunha</i>	1.8.2017
Clean from duplicates	<i>Ankica Barisic</i>	
Data extraction	<i>Ankica Barisic</i>	
Data synthesis	<i>Ankica Barisic</i>	
Internal analysis validation	<i>Ankica Barisic</i>	
External analysis validation	<i>Ankica Barisic</i>	
Complete technical report	<i>Ankica Barisic</i>	
Write paper	<i>Ankica Barisic</i>	
Review of report and paper	<i>Jacome Cunha</i>	

## RELATED WORK

There are systematic literature reviews on different topics in software engineering, but so far none has been conducted that investigates the relation between sustainability and modeling of CPS. An original contribution of our effort is that for the first time in this research field, we have followed an SLR method to be as objective as possible in our selection of primary studies. However, we examine in detail SLR protocol from related work. Related studies provide the necessary instruments to replicate the study, or in our case to extend them to cover new research.

### 2.1 Related studies

**Koziolk et al.** [5], reports on Sustainability Evaluation of Software Architectures: A Systematic Review. The contribution of this paper is a SLR on methods and metrics for evaluating the sustainability of software architectures. Their review carefully analyses existing scenario-based methods for their suitability to evaluate sustainability and additionally provides a survey and analysis of more than 40 architecture-level metrics. Authors find integration of scenario-based and metrics-based methods is useful to provide a continuous, pro-active approach towards evolution problem throughout the entire system life-cycle.

**Penzenstadler et al.** [8], reports on Sustainability in software engineering: A systematic literature review.. Authors aim to provide an overview of different aspects of sustainability in software engineering research with regard to research activity, investigated topics, identified limitations, proposed approaches, used methods, available studies, and considered domains. Conclusion is that there is little research coverage on the different aspects of sustainability in software engineering while other disciplines are already more active.

**Penzenstadler et al** [9], further performs Systematic Mapping Study on Software Engineering for Sustainability (SE4S) as follow up on the previous work with a more in-depth overview of the status of research, as most work has been conducted since 2011. The applied method is a systematic mapping study through which we investigate which contributions were made, which knowledge areas are most explored, and which research type facets have been used, to distill a common understanding of the state-of-the-art. Authors contribute an overview of current research topics and trends, and their distribution according to the research type facet and the application domains. Furthermore, they aggregate the topics into clusters and list proposed and used methods, frameworks, and tools. The research map shows that impact currently is limited to few knowledge areas and there is need for a future road map.

**Calero et al.** [1], perform A Systematic Literature Review for Software Sustainability Measures to discover the state-of-the art in software sustainability measures. The main goal was to obtain software sustainability measures for the quality characteristics and sub-characteristics identified in the 25010+S quality model, especially those that we have considered related to sustainability or that can be adapted to take into account aspects of it. In order to do that the digital libraries of ACM and IEEE as well as specific forums on Software Sustainability have been studied. As a result 16 papers were chosen. A total of 82 measures were extracted from these papers, although only 61 are useful for our quality model. The rest of the measures are for software process, for quality of Service-QoS or at company level. Regarding the product quality characteristic in which the measures can be applied, there are only measures for the following five characteristics: Performance efficiency, Maintainability, Portability, Usability, Reliability. Furthermore, many of the measures are focused on power consumption. Only two measures were found for sustainability in use.

**Moghaddam et al.** [7], conducted SLR on Energy-Efficient Networking Solutions in Cloud-Based Environments. This review outlines the state of the art in energy-efficient networking solutions in cloud-based environments. All of the primary studies demonstrate a growing attention to the problem and a lively and dynamic research space. Authors show that the Decision framework is the most frequently investigated solution type to accomplish the energy-efficiency goal. The main advantage of decision frameworks compared to other solutions is their ability to use other supporting techniques, such as programming of networks and pattern discovery.

**Lun et al.** [6], published Cyber-Physical Systems Security: a Systematic Mapping Study. This study aim at identifying, classifying, and analyzing existing research on CPS security in order to better understand how security is actually addressed when dealing with CPS. Authors empirically define a comparison framework for classifying methods or techniques for CPS security. From the collected data authors observe that even if solutions for CPS security has emerged only recently, in the last years they are gaining a sharply increasing scientific interest across heterogeneous publication venues. The systematic map of research on CPS security provided here is based on, for instance, application

fields, various system components, related algorithms and models, attacks characteristics and defense strategies.

**Gunes et al.** [2], presents A Survey on Concepts, Applications, and Challenges in Cyber-Physical Systems. In order to shed some light on the origins, the terminology, relatively similar concepts, and today's challenges in CPS, authors presented survey on related literature discussing practical applications and dominant research domains. Since CPS is a very broad research area, CPSs span diverse applications in different scales. Therefore, each application necessitates strong reasoning capabilities with respect to unique system-level requirements/challenges, the integration of cutting-edge technologies into the related application, and overall impact on the real world. Authors conclude that existing legacy systems have limited awareness of the CPS requirements, and that revolutionary design approaches are necessary to achieve the overall system objectives.

## 2.2 Research questions from related studies

We analyzed research questions from related studies and analyse what we can retrieve and reuse from the answers to related questions. Analysis is presented in Table 2.1.

First we highlight sustainability related studies which impacted our **RQ2** and some of existing results can be reused as explained further. Koziolok et al. [5] retrieve architecture based sustainability metrics and methods, which we will take in consideration to analyze if they are appropriate to be used in a context of CBS. Penzenstadler et al. [8],[9], retrieves that approaches which support sustainability has tendency to be domain-specific. Her work highlight a boost of the sustainability related research from 2011. Further she highlight the categorization of sustainability related methods which we reuse in our SLR. Further, the models and metrics which support sustainability assessment in software engineering are highlighted and will be further analyzed to understand their appropriateness for the Calero et al. [1] confirms ones more boost of sustainability research from 2011 and reports on over 100 sustainability measures and five quality metrics. Moghadam et al. [7] reports on strategies, solutions, technologies and evaluation methods for energy-efficient networking solutions.

Further, we analyzed studies related to CPS which impacted our **RQ1**. Lun et al. [6] lists application fields related to CPS. Gunes et al. [2] provides categorization of application domain for CPS. Therefore we would also like to get idea which application domains were addressed in our SLR by answering **RQ3**. Further Gunes et al. highlight sustainability as a one of important challenges to be addressed withing CPS field, by this supporting a need to address our main research concern which we plan to address by answering our **RQ4**.



Table 2.1: Related research question

	Id	Question	Retrieved	Status
[5]	RQ1	How do scenario-based architecture evaluation methods used in industry support sustainability evaluation?	Method	2
	RQ2	Which architecture-level metrics have been proposed to analyse the sustainability of software architectures?	Metric	50-60
	RQ3	What implications can be derived for the industrial and research communities from the findings?	Suggestions	5
[8]	RQ1	How much activity was there in the last 20 years (1991-2011)?	Query based number	
	RQ2	What research topics are being addressed?	domain-specific	
	RQ3	What are the limitations of current research?	complexity, domain specificity	
	RQ4	How is sustainability support performed?	model + metrics	19
	RQ5	Which methods are in use?	categorization	reused
	RQ6	Are there case studies available?		
	RQ7	Which domains are already considered?		
[9]	RQ1	What research topics are being addressed?	Topics by knowledge areas	10
	RQ2	How have these research topics evolved over time?	Boost from 2011	
	RQ3	How is sustainability support performed (e.g., models and methods)?	models & methods	14
	RQ4	Which of those models and methods are used in practice?	Evaluation & experience	9
	RQ5	Which research type facets have been considered in the contributions?	Knowledge areas	
	RQ6	Which application domains have been considered?	Application domains	reused
	RQ7	Which research groups are most active and what is the distribution		
[1]	RQ1	How much activity was there in the last 20 years?	Boost from 2011	
	RQ2	Are there software sustainability measures and indicators proposed in the literature?	Measures in general	>100
	RQ3	What sustainability aspects have been paid more attention?	Quality characteristics	5
	RQ4	What are the limitations of current research?		
	RQ5	Are there measures proposals that fit on the 25010+S model?	measures	17
[7]	RQ	What are the energy-efficient networking solutions in cloud-based environments?	Strategies Solutions Technologies Evaluation methods	11 10 10 4
[6]	RQ1	What are the publication trends of research studies on cyber-physical systems security?	Application files	2
	RQ2	What are the characteristics and focus of existing research on cyber-physical systems security?		
	RQ3	What are the validation strategies of existing approaches for cyber-physical systems security?		
[2]	Q1 Q2	Application domains Challenges	Categorization Sustainability	7

## 2.2. RESEARCH QUESTIONS FROM RELATED STUDIES

Table 2.2: Search queries

	<b>Query</b>	<b>Period</b>
[5]	software architecture AND (evolvability OR evolution OR maintainability OR maintenance OR 'qualitative evaluation' OR 'quantitative evaluation' OR 'scenario-based evaluation' OR metrics OR modifiability OR modularization OR sustainability)	till 2011
[8]	(sustainab* OR environment* OR ecolog* OR green) AND (software engineering OR requirement OR software system)	1991-2011
[9]	(sustainab* OR ecolog* OR green) AND (software engineering OR requirement* engineering OR requirement* specification OR software specification OR system specification)	1989-2013
	(sustainab* OR environment* OR ecolog* OR green) AND (software engineering OR requirement OR software system)	
[1]	(sustainab* OR environment* OR ecolog* OR green) AND (software measure* OR software metric* OR software indicators)	2003-2014
[7]	routing "data-center" network cloud (intitle:energy OR intitle:power) -intitle:mobile -intitle:telecom -intitle:wireless -intitle:hoc -intitle:radio -intitle:smart	2008-2013
[6]	((("cyber physical" OR "cyber-physical" OR cyberphysical OR "networked control") AND system*) OR CPS OR NCS) AND (attack* OR secur* OR protect*)	2006-2015

Table 2.3: Research sources from related work

<b>Used in</b>	<b>Automatic search</b>	<b>Used in</b>	<b>Manual search</b>
[5], [8],[9],[1], [6]	<b>ACM</b>	[9]	<b>ICT4S'13,</b>
[5], [8],[9],[1], [6]	<b>IEEE</b>	[9]	<b>GREENS'13</b>
[5], [8],[9], [6]	<b>SD</b>	[9]	<b>RE4SuSy'13</b>
[5], [8],[9], [6]	<b>SL</b>	[1]	<b>GREENS'12</b>
[5]	<b>GS</b>	[1]	<b>RE4SuSy'12</b>
[5]	<b>EL</b>	[6]	<b>HiCoNS</b>
[8],[9], [7], [6]""	<b>WS</b>	[6]	<b>IJCIP</b>
[9]	<b>DBLP</b>	[6]	<b>ISRCS</b>
[9]	<b>INSPEC</b>		
[9]	<b>JSTOR</b>		
[9]	<b>arXiv</b>		
[9], [6]	<b>Wiley</b>		
[9]	<b>Citeseer</b>		

## 2.3 Related queries and sources from related studies

In this section we list the queries used in related work to perform the automatic search in Table 2.2. We find that "(sustainab\* OR environment\* OR ecolog\* OR green)" is most complete query for sustainability search. Also, we note that related work considered literature before 2011 in all cases and in most cases before 2000.

Further, we present in Table 2.3 all sources (automatic and manual) which were taken in consideration in related work. We can note that most of related studies did made automatic search over the ACM Digital Library (ACM), IEEEExplore (IEEE), Science Direct (SD) and Springer Link (SL).

## 2.4 Keywords and definitions from related work

In this section we present definitions of main keywords relevant for our SLR taken from the related studies.

**Sustainability** is defined as 'a software-intensive system is long-living if it must be operated for more than 15 years. A long-living software system is sustainable if it can be cost-efficiently maintained and evolved over its entire life-cycle' [5].

**Sustainable development** 'meet the needs of the present without compromising the ability of future generations to satisfy their own needs. Sustainable development needs to satisfy the requirements of the three dimensions of society, economy, and environment. A fourth dimension, human sustainability, is less present in the public discussion' [8].

**Human sustainability** 'refers to the maintenance of the private good of individual human capital. The health, education, skills, knowledge, leadership and access to services constitute human capital' [8].

**Social sustainability** 'means maintaining social capital and preserving the societal communities in their solidarity. Social capital is investments and services that create the basic framework for society: trust lowers transaction costs' [8].

**Economic sustainability** is defined as economic capital. 'Economic capital should be maintained. The definition of income as the amount one can consume during a period and still be as well off at the end of the period can define economic sustainability, as it devolves on consuming value-added (interest), rather than capital' [8].

**Environmental sustainability** 'although it is needed by humans, it itself seeks to improve human welfare by protecting natural resources. These are water, land, air, minerals and ecosystem services; hence much is converted to manufactured or economic capital. Environment includes the sources of raw materials used for human needs, and ensuring that sink capacities recycling human wastes are not exceeded [8].

**Sustainable Software** 'can be interpreted in two ways: (1) the software code being sustainable, agnostic of purpose, or (2) the software purpose being to support sustainability goals, i.e. improving the sustainability of humankind on our planet. Ideally, both

interpretations coincide in a software system that contributes to more sustainable living. Therefore, in our context, sustainable software is energy-efficient, minimizes the environmental impact of the processes it supports, and has a positive impact on social and/or economic sustainability (1 2). These impacts can occur direct (energy), indirect (mitigated by service) or as rebound effect' [9].

**Sustainable Software Engineering** is 'the art of defining and developing software products in a way so that the negative and positive impacts on sustainability that result and/or are expected to result from the software product over its whole lifecycle are continuously assessed, documented, and optimized' [1].

Penzenstadler et al. [8] categorize methods which are used to address sustainability:

- Entity-relationship modeling - used as means to represent their data, knowledge, or information models;
- Neural networks - used for dynamic environments and simulations;
- Cost calculations;
- Life cycle analysis ;

**Cyber-physical systems (CPS)** 'are integrations of computation, networking, and physical processes. The key characteristic of cyber-physical systems is their seamless integration of both hardware and software resources for computational, communication and control purposes, all of them co-designed with the physical engineered components' [6].

**Sustainability of CPS** 'means being capable of enduring without compromising requirements of the system, while renewing the system's resources and using them efficiently. A highly sustainable system is a long lasting system which has self-healing and dynamic tuning capabilities under evolving circumstances. Sustainability from energy perspective is an important part of energy provision and management policies. For example, the Smart Grid facilitates energy distribution, management, and customization from the perspective of customers or service providers by incorporating green sources of energy extracted from the physical environment. However, intermittent energy supply and unknown/ill-defined load characterization hinders the efforts to maintain long-term operation of the Smart Grid. To maintain sustainability, the Smart Grid requires planning and operation under uncertainties, use of real-time performance measurements, dynamic optimization techniques for energy usage, environment-aware duty cycling of computing units, and devising self-contained energy distribution facilities (such as autonomous micro grids). [2]

Gunes address sustainability as one of main challenge for CPS (see Figure 2.1) and he identify its subcharacteristics as follows:

**Adaptability** - "Adaptability refers to the capability of a system to change its state to survive by adjusting its own configuration in response to different circumstances in



Figure 2.1: CPS challenges [2]

the environment. A highly adaptable system should be quickly adaptable to evolving needs/circumstances. Adaptability is one of the key features in the next generation air transportation systems (e.g. NextGen). NextGen's capabilities enhance airspace performance with its computerized air transportation network which enables air vehicles immediately to accommodate themselves to evolving operational environment such as weather conditions, air vehicle routing and other pertinent flight trajectory patterns over satellites, air traffic congestion, and issues related to security "[2].

**Resilience** - "Resilience refers to the ability of a system to persevere in its operation and delivery of services in an acceptable quality in case the system is exposed to any inner or outer difficulties (e.g. sudden defect, malfunctioning components, rising workload etc.) that do not exceed its endurance limit. A highly resilient system should be self-healing and comprise early detection and fast recovery mechanisms against failures to continue to meet the demands for services. High resilience comes into play in delivering mission-critical services (e.g. automated brake control in vehicular CPS, air and oxygen flow control over an automated medical ventilator etc.). Mission-critical CPS applications are often required to operate even in case of disruptions at any level of the system (e.g. hardware, software, network connections, or the underlying infrastructure). Therefore, designing highly resilient CPS requires thorough understanding of potential failures and disruptions, the resilience properties of the pertinent application, and system evolution due to the dynamically changing nature of the operational environment "[2].

**Reconfigurability** -"Reconfigurability refers to the property of a system to change its configurations in case of failure or upon inner or outer requests. A highly reconfigurable system should be self-configurable, meaning able to fine-tune itself dynamically and coordinate the operation of its components at finer granularities. CPSs can be regarded as autonomously reconfigurable engineered systems. Remote monitoring and control mechanisms might be necessity in some CPS application scenarios such as international border monitoring, wildfire emergency management, gas pipeline monitoring etc. Operational

Table 2.4: Functionality of CPS Domains Type of Domain Scale/Functionality [2]

<b>Smart Manufacturing</b>	Medium Scale, optimizing productivity in the manufacture of goods or delivery of services;
<b>Emergency Response</b>	Medium/Large Scale; handling the threats against public safety, and protecting nature and valuable infrastructures;
<b>Air Transportation</b>	Large Scale; operation and traffic management of aircraft systems;
<b>Critical Infrastructure</b>	Large Scale; distribution of daily life supplies such as water, electricity, gas, oil;
<b>Health Care and Medicine</b>	Medium Scale, monitoring health conditions of the patients and taking necessary actions;
<b>Intelligent Transportation</b>	Medium/Large Scale, improving safety, coordination and services in traffic management with real-time info sharing;
<b>Robotic for Service</b>	Small/Medium Scale, performing services for the welfare of humans;

needs (e.g. security threat level updates, regular code updates, efficient energy management etc.) may change for such scenarios, which calls for significant reconfiguration of sensor/actuator nodes being deployed or the entire network to provide the best possible service and use of resources "[2].

**Efficiency** - "Efficiency refers to the amount of resources (such as energy, cost, time etc.) the system requires to deliver specified functionalities. A highly efficient system should operate properly under optimum amount of system resources. Efficiency is especially important for energy management in CPS applications. For example, smart buildings can detect the absence of occupants and turn off HVAC (Heating, Ventilation, and Air Conditioning) units to save energy. Further, they can provide automated pre-heating or pre-cooling services based on the occupancy prediction [2].

Various studies have addressed the domains and domain specific applications of CPS. Gunes et al. [2] summarize a number of research efforts that address some of those domains, namely Smart Manufacturing, Emergency Response, Air Transportation, Critical Infrastructure, Health Care and Medicine, Intelligent Transportation, and Robotic for Service (see Table 2.4). We reused this categorization for identification of application domains for CPS (which address our RQ3), and here we present the definitions of terms from Gunes et al. [2].

**Smart manufacturing** 'refers to the use of embedded software and hardware technologies to optimize productivity in the manufacture of goods or delivery of services. Smart factory is another frequently mentioned concept to refer to the next generation smart manufacturing. Smart manufacturing is one of the leading CPS application domains because of drivers like mass production, domestic and international marketing, economic growth, etc. A large effort on characterizing CPS for smart manufacturing has been undertaken in Europe and the U.S. The Industrie 4.0 project is a German strategic initiative, which represents a major opportunity for manufacturing of the future. A



non-profit organization, namely the Smart Manufacturing Leadership Coalition (SMLC), was established in the U.S. SMLC involves manufacturing supplier, practitioner, and consortia, technology companies, universities, and government labs that have expressed interest in realizing smart manufacturing of the future' [2].

**Emergency response** 'refers to handling the threats against public safety, health, and welfare and protecting the nature, properties, and valuable infrastructures. CPS can provide fast emergency response via large number of sensor nodes in the regions in case of the natural or man-made. disasters. However, this rapid response requires the nodes to collectively assess the situation and rapidly inform the central authority even in the frequently-changing environments. So robustness, effective resource utilization, adaptiveness, and timeliness come into play in this emergency response' [2].

**Air transportation** refers to any civil or military aviation systems and their traffic management. Smart air vehicles are expected to be predominant in the near future, especially for military service. The Unmanned Aerial Vehicle (UAV), commonly known as the drone, is just one of the well-known examples of smart air vehicles. Since physical-awareness is an important issue for the next generation air vehicles, CPSs are expected to make a profound impact on the future aviation and Air Traffic Management (ATM). Distributed control throughout the airspace is expected to become a substantial part of the next generation ATM systems. However, that would give rise to more scalability challenges since interactions between vehicles and infrastructure are becoming more complicated. Current capacity constraints at the major airports and airspace interactions between the airports and air vehicles in a multi-airport system limit the overall capacity of the system. Today, air traffic control is managed through radar towers and computing support systems have limited physical awareness. So, tight integration of the computational and physical capabilities is of paramount importance for the next generation air transportation systems' [2].

**Critical infrastructure** 'refers to valuable properties and public infrastructures that are necessary for the survival or welfare of the nations. The Smart Grid is one of the appealing applications in the critical infrastructure domain. The Smart Grid incorporates central/industrial power plants, energy storage and transmission facilities, renewable energy resources (such as wind farms and solar cells), and energy distribution and management facilities in smart homes/buildings. The Smart Grid describes the transformation from a centralized, producer-controlled network of electricity grid to a less centralized, more distributed, more cooperative, more responsive, and more consumer-interactive one by bringing future information and communication technologies and power system engineering together for grid modernization. Besides the Smart Grid, water distribution is another important service for the communities. The SmartAmerica Challenge project introduces an enhanced water distribution infrastructure challenge enabled by cellular based CPS that will eventually provide real-time monitoring of water quality and flow control; faster response to possible contamination; low cost and more secure water; and better leak detection' [2].

**Health care and medicine** 'refers to the issues addressing multiple aspects of the patient's physiology. A special attention is drawn to medical applications in CPS research since they provide significant research opportunities for the CPS community. These opportunities include, but are not limited to, technologies related to home care, assisted living, smart operating room, smart medical devices (e.g. pace maker, medical ventilator, infusion pump etc.), and smart prescription. Today, medical technology only provides limited access and integration of data along with manual coordination of medical devices and loops are not closed. The Cyber-Physical Medical Systems of the future should provide extensive data integration and access, comprehensive data acquisition and analysis, closed loop control capabilities, energy efficiency, real-time visualization, and plug-and-play capability with interoperable medical devices' [2].

**Intelligent transportation** 'refers to the advanced technologies of sensing, communication, computation, and control mechanisms in transportation systems to improve safety, coordination, and services in traffic management with real-time information sharing. Intelligent transportation facilitates both ground and sea transportation through information sharing over satellites and provides communication environment among vehicles, the infrastructure, and passengers' portable devices. The Intelligent Transportation Systems (ITSs) integrate pedestrians, vehicles, sensors, road-side infrastructures, traffic management centers, satellites, and other transportation system components by adopting different variation of wireless communication technologies and standards. ITSs of the future allow real-time traffic monitoring; increase in transportation safety and comfort through information exchange among traffic users; optimal traffic management; collision avoidance; and utilization of satellite based technology to connect drivers, roads, and vehicles smoothly. With the integration of CPS into infrastructures, vehicles, and roadways, ITSs can achieve driver assistance, collision avoidance or notification, improvements in travel time without fear of unexpected delays, reductions in congestion, and advanced control over infrastructure and vehicles for energy saving. ITSs rely not only on advanced sensor and embedded computer systems technology but also on wireless, cellular, and satellite technologies for vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), and vehicle-to- infrastructure (V2I) communication to better manage complex traffic flow, ensure safety, and extend situational awareness' [2].

**Robotic for service** 'refers to deploying intelligent robots to perform services for the welfare of humans, and the equipment in a fully autonomous, semi-autonomous, or remotely controlled manner, excluding manufacturing operations. Robotic for service is identified as one of the six disruptive civil technologies with potential impacts on the U.S. interests out to 2025. Robots can be deployed for several purposes, including but not limited to defense (e.g. explosive disposal, surveillance in prohibited areas, etc.), environment monitoring and control, assisted living, logistics, and so on. Since the next generation robots are likely to have close interactions with humans in the physical environment of their operation, learning and interpretation of human activities by the robots comes into play as an important factor. From CPS perspective, integration of humans and



smart robots is very important to enable all actors of CPSs to achieve better cooperation, collaboration, and organization to overcome complex duties' [2].

**Building automation** 'refers to the deployment of various sensors, actuators, and distributed control systems to provide optimum control and automation of heating, ventilation, air conditioning (HVAC), lighting, fire prevention, and security systems in the buildings. Smart/intelligent building is a frequently mentioned concept to address the next generation buildings. Smart buildings are needed to fulfill the vision of the Smart Grid and Smart City concepts. With the growing popularity, IoT/CPS provides great opportunities for new applications in the next generation building automation concept via a large range of smart building appliances including entertainment media as well, which in return brings diverse requirements and interaction patterns for realizing such systems [81]. Besides being applied in homes and offices, building automation from CPS perspective can be applied to laboratories. Since activities done in laboratories have been getting sophisticated due to technological advances, new arrangements and services, such as regulation of environmental conditions due to environment-sensitive equipment, accessing incidents or abnormalities, tracing dangerous materials, harvesting energy etc., are needed for the management of laboratories in the future' [2].

## REVIEW METHODS

In this section we present the protocol defined to address research questions presented in Section 1. The additional details about protocol and research results can be found in online Excel file <sup>1</sup>.

### 3.1 Data sources and search strategy

It is specified that our SLR will address the period from **2011-2017** as it is confirmed within related research that interested on topic of sustainability boosted from 2011 (see Section 2.2).

Data sources were carefully selected and validated during the Protocol Review Session to include the most relevant journal, conferences and international peer-reviewed workshop that are concerned with the topic of sustainability or CPS (see Table 3.1). The existing venues covered by the previous SLRs were also included in the case they were still actual in a defined period (2011-2017). For the automated scan of the Search Process we selected the digital libraries which were addressed by most of related studies (see Section 2.3). Namely,

- ACM Digital Library (ACM)
- IEEExplore (IEEE)
- Science Direct (SD)
- Springer Link (SL)

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<sup>1</sup><https://goo.gl/cqc963>

Table 3.1: Manual search sources

Acronym	Source Name	Venue
GREENS	International Workshop on Green and Sustainable Software	2012-2016
RE4SuSy	International Workshop on Requirements Engineering for Sustainable Systems	since 2011
SMARTGREENS	International Conference on Smart Cities and Green ICT Systems	since 2012
	Proceedings of the The First Workshop on Verification and Validation of Cyber-Physical Systems	since 2016
	ACM Workshop on Cyber-Physical Systems-Security and/or PrivaCy	since 2015
MPM4CPS	Multi-paradigm modelling for Cyber-physical systems COST network	since 2014
Sustainability@Bellairs	Modelling for sustainability	since 2015
ICCPs	ACM/IEEE International Conference on Cyber-Physical Systems.	since 2009

## 3.2 Search query

Here we highlight most influencing quarry test which helped us to define our research query (see Table 3.2). All quarries reused parts from the related work research strings (see Table 2.2). Among different attempts, which are all listed in detail in our protocol, we highlight the following ones:

**Q3** - (sustainab\* OR environment\* OR ecolog\* OR green) AND ((“cyber physical” OR “cyber-physical” OR cyberphysical OR smart) AND system\*) AND ("modelling"OR "modeling") AND ("software engineering"OR requirement OR "software system")

**Q2** - (sustainab\* OR environment\* OR ecolog\* OR green) AND ((“cyber physical” OR “cyber-physical” OR cyberphysical OR smart) AND system\*) AND ("modelling approach"OR "modeling approach"OR "integrate modelling"OR "integrate modeling") AND ("software engineering"OR requirement OR "software system")

The Q3 resulted in too many papers due to the use of word 'modelling', while the Q2 was the quarry selected before the review workshop. The number of papers resulted for each quarry are presented in Table 3.2. After review session, we received recommendation to include the energy efficiency variations to the part of string which address sustainability. Also, we included the 'model-driven' in a keywords selected to include the modelling approaches. Based on this our research quarry which is to be used in this SLR is defined as

**Q1** - (sustainab\* OR environment\* OR ecolog\* OR green OR "energy efficien\*"OR "energy-efficien\*") AND ((“cyber physical” OR “cyber-physical” OR cyberphysical OR smart) AND system\*) AND ("modelling approach"OR "modeling approach"OR "integrate modelling"OR "integrate modeling"OR "model driven"OR "model-driven")

Table 3.2: Testing research quarries over digital libraries

Database:	Search string:	since 2011	since 2001
ACM	Q3	103	169
	Q2	1	2
	Q1	4	6
IEEE	Q3	44704	49188
	Q2	15	17
	1IEEE1	15	17
	1IEEE2	39	41
SD	Q3	3139	4072
	Q2	284	329
	Q1	447	555
SL	Q3	4439	5856
	Q2	347	449
	Q1	414	518
Sum:	Q3	52385	59285
	Q2	647	797
	Q1	919	1137

#### AND ("software engineering"OR requirement OR "software system")

This quarry resulted in just a bit higher number of papers to be included. Further, for the IEEE database research we needed to brake it in following substrings:

**1IEEE1** - (sustainab\* OR environment\* OR ecolog\* OR green) AND (("cyber physical" OR "cyber-physical" OR cyberphysical OR smart) AND system\*) AND ("model driven"OR "model-driven") AND ("software engineering"OR requirement OR "software system")

**1IEEE2** ("energy-efficien\*"OR ("energy efficien\*")) AND (("cyber physical" OR "cyber-physical" OR cyberphysical OR smart) AND system\*) AND ("modelling approach"OR "modeling approach"OR "integrate modelling"OR "integrate modeling") AND ("software engineering"OR requirement OR "software system")

Also, as we performed the search between Q2 and Q1 within one month difference we observed that set of papers returned by the Springer reduced. For that we decided to merge the papers returned by first and second attempt. This might be due to fact that we used the classification for 'Computer Science' paper on springer. However, seems that this categorization was changed in digital library over time.

### 3.3 Study selection criteria

The studies that were included are the ones that report modelling of CPS or/and sustainability assessment and are reported from the 2011. The studies that are part of informal literature, present duplicated work or its extension and ones that are not in English are not also considered (see Table 3.3 for detail criteria).

Table 3.3: Inclusion and exclusion criteria

<b>Id</b>	<b>Type</b>	<b>Criteria</b>
E1	Exclusion	Informal literature (power point slides, conference reviews, informal reports) and secondary/tertiary studies (reviews, editorials, abstracts, keynotes, posters, surveys, books).
E2	Exclusion	Duplicated papers.
E3	Exclusion	Papers that did not apply to research questions i.e. did not report the method for sustainability or modeling approach for CPS
E4	Exclusion	Papers with the same content in different paper versions.
E5	Exclusion	Papers written in other than English language.
E6	Exclusion	Purely hardware, or electrical engineering perspective papers
E7	Exclusion	Purely application of sustainability in environmental domains (e.g. agricultural papers)
E8	Exclusion	* Environmental used only in the context of technical (operational) environment of CBS, and not the impact on environment
E9	Exclusion	Secondary study
I1	Inclusion	Publication date from 1/1/2011
I2	Inclusion	Relevance with respect to research questions
I3	Inclusion	Explicit mentioning of cyber-physical system
I4	Inclusion	Papers that report a methodology, metric or model for sustainable software system
I5	Inclusion	Papers that report a methodology, metric or model for CPS
I6	Inclusion	Analysis of sustainability relevant application domains

Table 3.4: Self Assessment Criteria

<b>Id</b>	<b>Self-Assessment Criteria</b>	<b>Score</b>
SA1	Reviewers confidence about content of the study	1 = Very confident    0.5 = Confident    0 = Not very confident
SA2	Reviewers confidence about quality of the study	1 = Very confident    0.5 = Confident    0 = Not very confident

### 3.4 Study quality assessment

To have means to reflect a confidence of reviewer, we defined two self-assessment points (see Table 3.4). In a case that a reviewer is not very confident about the paper, the additional reviewer will be asked to make revision and the assessment scores will be discussed.

In order to assess the quality of selected studies the criteria was defined in order to rank the quality of each paper (see Table 3.5). To characterize a first criteria (relevance of journal or conference), we decided to use **CORE2017**<sup>2</sup> conference ranks list. For the second criteria \* apply for paper published before 2014; while \*\* for paper published 2014 and after. We did not define any exclusion criteria regarding the quality of study, but we find it meaningful to present a statistics on the end and observe if it does make any impact.

<sup>2</sup><http://portal.core.edu.au/conf-ranks/>

Table 3.5: Quality Assessment Criteria

<b>Id</b>	<b>Assessment Criteria</b>	<b>Score</b>			
QA1	What is the relevance of the paper according to the conference/journal where it was published?	1 = Very relevant (A)	0.5 = Relevant (B)	0 = Not so relevant	
QA2	What is the relevance of the citation according to its related citations?	1 = High (*>5; **>0)	0.5 = Medium (*>0; **=0)	0 = Low (*=0)	
QA3	How clearly is the problem of study described?	1 = Explicitly	0.5 = Vaguely	0 = No description	
QA4	How clearly is the research context stated?	1 = With references	0.5 = Generally	0 = Vaguely	
QA5	How rigorously is the method evaluated?	1 = Empirical foundation	0.66 = Case study	0.33 = Lessons Learned	0 = No evaluation
QA6	How explicitly are the contributions presented?	1 = Explicitly	0.5 = Generally	0 = No presentation	
QA7	How explicitly are the insights and issues for future work stated?	1 = With recommendations	0.5 = Generally	0 = No statement	

### 3.5 Data Extraction Form

Data Extraction Form is created from four parts;

First part giving us the general information about the selected study, like who are authors and how many citations paper had (See Table 3.6). We took a number of citations reported by Google Scholar <sup>3</sup>. In this part we register who reviewed the given paper.

Second part is meant to collect information's that will help us to address the research questions (See Table 3.6). For RQ1, we are identifying if the paper report modeling approach for building CPS, and if it does we register if it report a model/meta-model, a tool or a process. For RQ2, we identify if the paper report approach for addressing sustainability and if it does we want to know if it report a technique/method that is used, a metric, or a sustainability/green model. Further we categorize technique/method addressed by Q2.1 in a Table 3.7 as it is proposed in related work (see Section 2.4). For RQ3, we register if the approach is domain- specific, and if it is we want to know which application domain is addressed. We categorize the application domains as proposed in related work in Table 3.7. Finally, for RQ4 we explicitly register if paper report modelling approach for addressing sustainability of CBS, which is actually a result of positive answer to the Q1 and Q2. For each of defined questions, if there is no

Third part of extraction form address the quality of the paper itself and is described in Quality Assessment Study (see Table 3.5).

<sup>3</sup><https://scholar.google.pt/>

Table 3.6: Data Extraction Strategy

<b>Paper</b>	
Id	
Author	
Title	
Year	
Venue	
CitaionKey	
Citations	
URL	
Reviewer	
<b>Research Questions</b>	
<b>RQ1</b>	Which modeling approaches exist for building CPS?
<b>Q1</b>	Does the paper report modeling approach for building CPS?
<b>Q1.1</b>	Does paper report a model/meta-model?
<b>Q1.2</b>	Does paper report a tool?
<b>Q1.3</b>	Does paper report a process?
<b>RQ2</b>	Which approaches for addressing sustainability exist?
<b>Q2</b>	Does the paper report approach for addressing sustainability?
<b>Q2.1</b>	Does the paper report technique/method that is used?
<b>Q2.2</b>	Does the paper report metric?
<b>Q2.3</b>	Does the paper report sustainability/green model?
<b>Q2.0</b>	(If Q2 = no) Does paper report on other qualitative assessment? Which?
<b>RQ3</b>	Which application domains have been considered?
<b>Q3</b>	Is approach domain specific?
<b>Q3.1</b>	Which application domain is addressed?
<b>RQ4</b>	Which modelling approaches for addressing sustainability of CBS exist?
<b>Q4</b>	Does the paper report modelling approach for addressing sustainability of CBS?

Table 3.7: Special categorizations

<b>Q2.1</b>	<b>Q3.1</b>
1- entity-relationship modeling	1 - Smart Manufacturing
2 - netural networks	2 - Emergency Response
3 - cost calculations	3 - Air Transportation
4 - life-cycle analysis	4 - Critical Infrastructure
	5 - Health Care and Medicine
	6 - Intelligent Transportation
	7 - Robotic for Service
	8 - Building automation

Table 3.8: Data Extraction example

1 Paper	
<b>Id</b>	1
<b>Author</b>	Gerostathopoulos, Ilias; Bures, Tomas; Hnetynka, Petr; Keznikl, Jaroslav; Kit, Michal; Plasil, Frantisek; Plouzeau, Noël
<b>Title</b>	Self-adaptation in software-intensive cyber-physical systems: From system goals to architecture configurations
<b>Year</b>	2016
<b>Venue</b>	Journal of Systems and Software
<b>CitaionKey</b>	Gerostathopoulos2016
<b>Citations</b>	3
<b>URL</b>	<a href="http://www.sciencedirect.com/science/article/pii/S0164121216000601">www.sciencedirect.com/science/article/pii/S0164121216000601</a>
<b>Reviewer</b>	Ankica Barisic
2 RQ	
RQ1	
<b>Q1</b>	1 - yes
<b>Q1.1</b>	1 - yes
<b>Q1.2</b>	2 - no
<b>Q1.3</b>	1 - yes
RQ2	
<b>Q2</b>	1 - yes self adaptability
<b>Q2.1</b>	1 - yes 4 - life-cycle analysis
<b>Q2.2</b>	2 - no
<b>Q2.3</b>	2 - no
<b>Q2alt</b>	
RQ3	
<b>Q3.1</b>	1 - yes
<b>Q3.2</b>	2 - Emergency Response military avionics case study
RQ4	
<b>Q4</b>	1 - yes
3 QA	
<b>QA1</b>	1 = Very relevant (A)
<b>QA2</b>	1 = High (*>5; **>0)
<b>QA3</b>	0.5 = Vaguely
<b>QA4</b>	0.5 = Generally
<b>QA5</b>	1 = Empirical foundation
<b>QA6</b>	0.5 = Generally
<b>QA7</b>	1 = With recommendations
4 SA	
<b>SA1</b>	0.5 = Confident
<b>SA2</b>	1 = Very confident



Finlay, fourth part define self-assessment which reflect the confidence of the reviewer (Likert scale from Not very confident 0, Confident 0.5 to Very confident 1) (see Table 3.4):

Confidence about content of the study – here the reviewer gives its confidence about if the content of the paper really report the modelling of CPS or a sustainability assessment (Part 2 of the form).

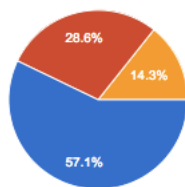
Confidence about quality of the study – here the reviewer gives self assessment of the confidence regarding answering the Quality Assessment questions (Part 3 of the form)

This form is to be filled for each study which is selected in the final Search Process phase, namely, after abstract review. The example of complete data extraction form can be seen in Table 3.8.

## PROTOCOL VALIDATION

The protocol was first validated during a workshop in which participated researchers from Software Systems NOVA-LINCS research group. After receiving the first opinions, the protocol was revised and documented in excel file <sup>1</sup>. A survey <sup>2</sup> was conducted as a part of the protocol evaluation process the excel file link served as the SLR protocol reference to guide participants review.

### What is your overall expertise concerning the SLRs?



I am a lecturer and/or publisher of SLR.	4	57.1%
I am knowledgeable in SLRs, though not an expert.	2	28.6%
I am not an expert. My evaluation is that of an informed outsider.	1	14.3%
Other	0	0%

Figure 4.1: Expertize of participants

The following researchers filled the form:

- Eric Rocha de Souza
- Jácome Cunha
- João Araujo
- Charlie Lopes
- Cristiano De Faveri
- Denise Lazzeri Gastaldo Bombonatti

<sup>1</sup><https://goo.gl/4CFjLw>

<sup>2</sup><https://docs.google.com/a/campus.fct.unl.pt/forms/d/1812KUcbgvUFkKvyWSCj40VxevFa4FnoOT6jQsKvcyas/edit>

- Enyo Gonçalves

We can see in Figure 4.1 that most of participants were experts in regarding SLR, while other had relevant knowledge. Only one participant reported to not be an expert.

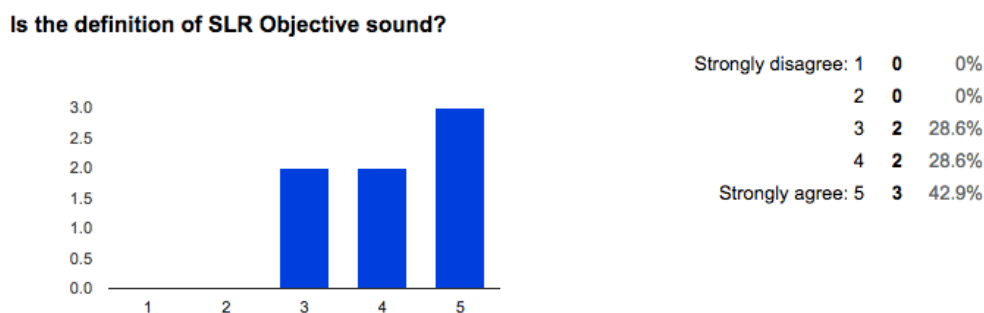


Figure 4.2: SLR Objective

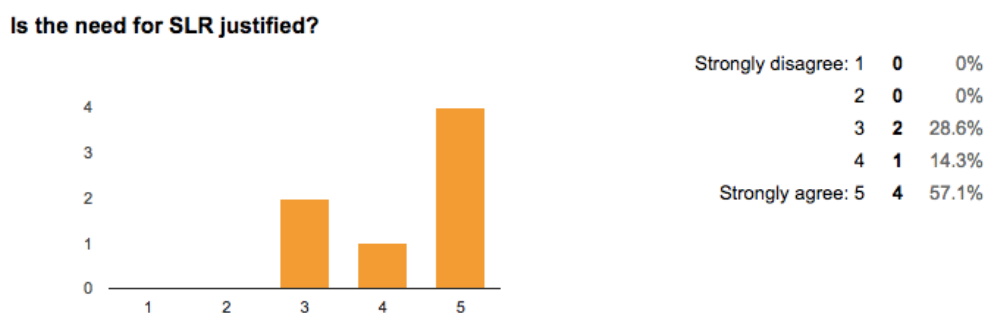


Figure 4.3: Need for SLR

Regarding protocol itself, we first asked participants to report their opinion on SLR Basic Data (see Figure 4.2 and Figure 4.3). Most of participants agree that objective is sound and a need for performing SLR is justified. We received a valuable feedback on how to improve our objectives and justification which were applied to revised protocol:

- Not clear why you are doing this SLR, what are the benefits, advantages to do all the work? Who will benefit from this?
- Why is there interest to perform an SLR in CPSs instead of other products? It is not clear for me why the SLR should focus only in sustainability attribute. Why dependability and usability are less important in this context? I suggest to justify the SLR scope in CPSs and specifically in sustainability. Some market impact studies, tendencies and other factors that can prove the SLR importance. Other point to be considered is the modelling point of view. Modelling is something wide. What aspects of modelling will be considered? Modelling activities, languages, tools? Will modelling ensure that sustainability will be embodied in CPSs products?

- I believe that the objective can be improved to: Identify and analyse modelling approaches for CPS regarding to sustainability concern.

**Do the research questions cover the specific work objective?**

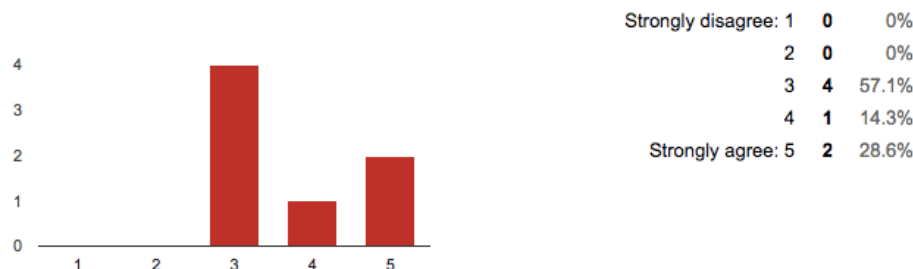


Figure 4.4: Research Question conform to Objective

**Are the research questions clear?**

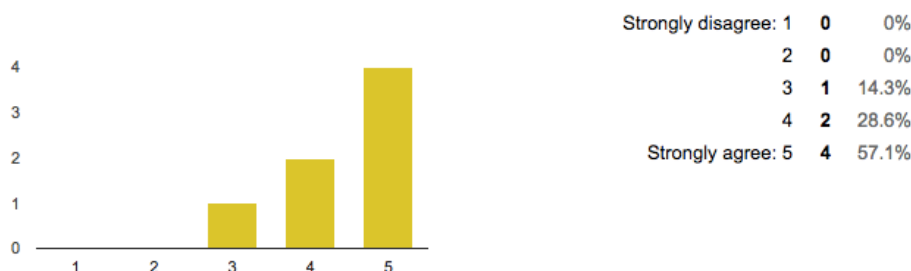


Figure 4.5: Clarity of Research Questions

Further, we assessed opinion and recommendations regarding our Research Questions (see Figure 4.4 and Figure 4.5). Reviewers agree that research questions cover our work objectives and are expressed clearly. We highlight following comments about research questions and our PICOC strategy:

- For me it is unclear to what RQ3 is referring to: is it to the modeling CPS or to the sustainability? Both can be applied to a particular domain. Maybe this question can be a sub-question of both RQ1 and RQ2.
- RQ4 seems quite similar to RQ1.1 In the RQ2.1 - Are there ones which can be applied to CPS? who is going to define whether the model can be applied to CPS? Are there any established criteria to define this? Or you are considering only those explicitly applied for CPS in the paper. Some additional ideas that could be identified during the SLR: a) Level of abstraction do these models b) If they are modelled using established languages, domain-specific, extensions, etc... c) If they intended to be design and/or runtime (models@run.time approach)
- I think questions R2+R2.1 overlaps R4 R1 are overlapped R2 as well. Green economy is sustainability subfactor? If it is a subfactor, why is this subfactor selected?

What is the relevance to ask about domain? Are you interested in some specific domain? What should be the conclusions by domain?

- The population also includes works for modeling CPS. Similar for intervention. The outcomes should be something like "Outcomes should point to techniques, methods and metrics that can be used to address the sustainability of CPS during their modeling/design phase"
- P: Are you interested in modelling languages, tools, approaches, existing models?  
I: What is the interest? A modelling language/tool/approach/existing models?  
C: Comparison between modelling languages/approaches/existing models will be performed? O: Metrics were not mentioned before... C: OK

Next, we assessed opinion and recommendations regarding our Search Sources (see Figure 4.6). Reviewers agree that selected conferences, journals and workshops are representative to the area of study and left following comments:

- Also include the ACM/IEEE International Conference on Cyber-Physical Systems.
- I know the specific workshops only, but I guess software engineering venues in general should be included
- I guess you can search also on modeling conferences. For example, ER and MODELS. Models@run.time workshop, if I'm not mistake, has some papers in this area.
- I suggest you add SCOPUS and ISI Web of Science

We did introduce the recommended CPS workshop, however other workshops we do not find to be so important to be examined manually. However, research works from these workshops are indexed by libraries we use as search sources. Also, we did test our string for library like Scopus, but we retrieve 1400 papers which gives for now too much primary studies for revision.

**Are the selected conferences, journals and workshops representative to the area of study?**

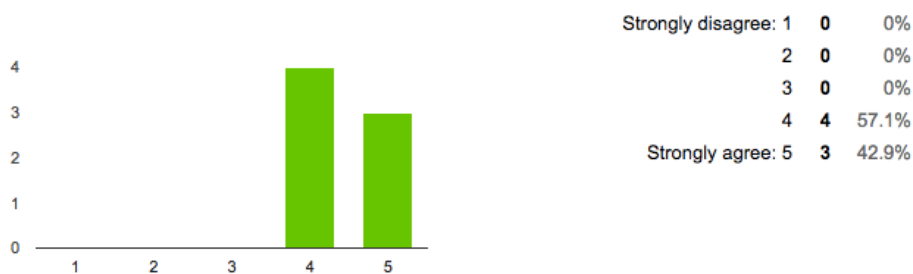


Figure 4.6: Search Sources

Next, we assessed opinion and recommendations regarding our Search Quarry (see Figure 4.7). Reviewers agree that selected keywords are sufficient for achieving a SLR objective Reviewers left following comments:

- I think we should also include energy efficiency in the first part of the string.
- Will metrics be considered? Other attributes will be added? Why was software engineering topic considered? I think keywords should be refined in case you have more specific definitions related to what you are looking for.
- Is INTELLIGENT a usual term to smart? Is model driven development/model driven engineering a suitable term to be grouped with Software Engineering?

We did include the term 'energy-efficient\*' and 'model-driven' to our final quarry as suggested by reviewers.

**Do the queries have the sufficient keywords to achieve SLR objectives?**

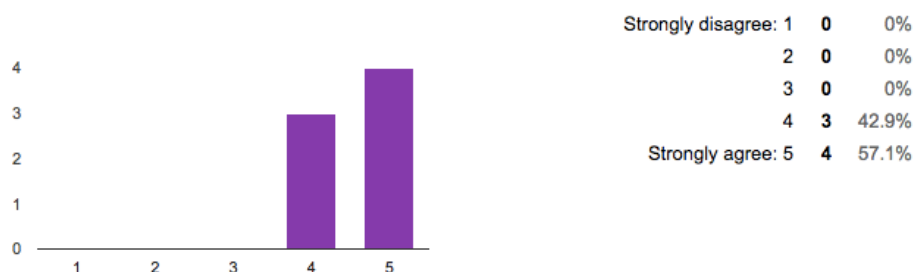


Figure 4.7: Search keywords sufficiency

Next, we assessed opinion and recommendations regarding our Inclusion and Exclusion Criteria (see Figure 4.8). Reviewers agree that defined criteria is complete enough to achieve the study objectives. Reviewers left following comments:

- Porque a partir de 2011? I2 - Que critérios indicam que um artigo é relevante? I3 - Tem critério pra dizer o que é "explicit Mentioning"? Acho que esse critério é muito genérico e pode não ser atendido devido aos outros critérios de inclusão
- - I'd put a range of dates for searching (such as from 01/01/2011 to 01/01/2017) to make the study replicable. I just wrote in a previous comment

**Are the inclusion/exclusion criteria complete enough to achieve the study objectives?**

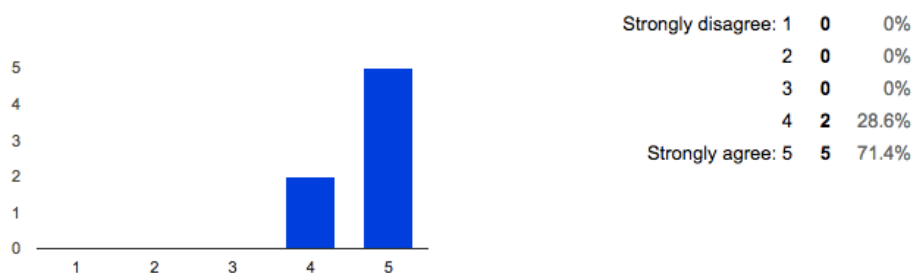


Figure 4.8: Inclusion and Exclusion Criteria

Next, we assessed opinion and recommendations regarding our Data Extraction Strategy (see Figure 4.9). Reviewers agree that defined extraction form is complete enough to achieve the study objectives. Reviewers left following comments:

- about the domain application, could have "other"
- In my opinion some definitions in data extraction form were not considered in keywords, for example,
- technique, method, metamodel, process, tool... Are you looking for all these items? I strongly suggest that you define what kind of analysis you will have after collecting all the data. Statistical analysis, charts, etc...
- You can include the identification of the context (Industrial or academic)...

**Is the data extraction Form complete enough to achieve SLR objectives?**

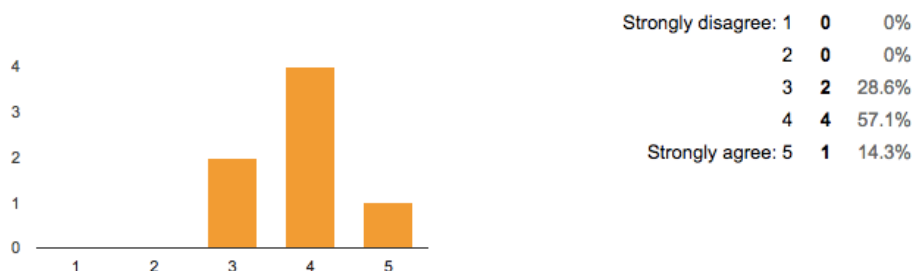


Figure 4.9: Inclusion and Exclusion Criteria

Next, we assessed opinion and recommendations regarding our Data Quality Assessment Strategy (see Figure 4.10). Reviewers strongly agree that defined quality assessment is complete enough to achieve the study objectives. Reviewers left only following comment:

- I suggest that you add the following QAC: Is there a motivation for the study realization?

**Are the quality assessment criteria complete enough to achieve SLR objectives?**

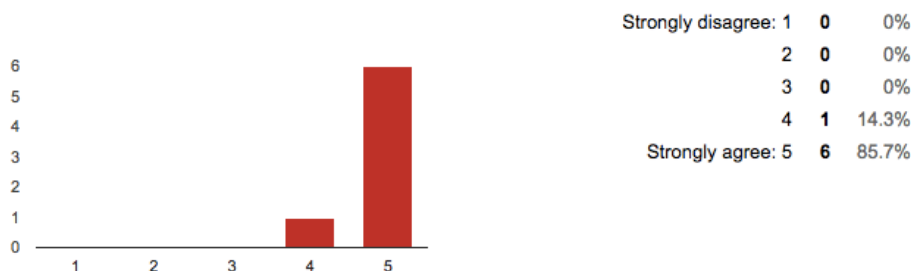


Figure 4.10: Inclusion and Exclusion Criteria

Finally, we asked reviewers to leave a other consideration related to this review:

- 
- I think you should change the type of research from SLR to systematic mapping study.
  - Parabéns pelo trabalho, sua planilha é bem detalhada. Tome meus comentários apenas como sugestões ou pontos que merecem alguma atenção, pois não sou especialista no assunto.
  - Regarding sustainability, the various terms related to the concept can lead to different interpretations during text analysis. In this sense, it is interesting to make clear how conflicts or uncertainty will be solved. As in every SLR, some parts of the protocol has to be refined as long as the papers are read and more detailed information is collected.
  - Thanks for considering me to participate in this review. I hope I could help with this initiative. Have a good luck in next steps!! With best regards Denise
  - I believe that you have a well-done SLR protocol. I wrote some suggestions about it... If you want to discuss about it, you don't hesitate... Contact me.

Reviewers took from 20min till 2h to complete this survey form. All in all they agree that a protocol is complete enough to address our research objectives. Expect this recommendation we did obtained the relevant suggestions which we used to clarify better our protocol and improve it.





## BIBLIOGRAPHY

- [1] C. Calero and M. F. Bertoa. “A Systematic Literature Review for Software Sustainability Measures.” In: (2013).
- [2] V. Gunes, S. Peter, T. Givargis, and F. Vahid. “A Survey on Concepts, Applications, and Challenges in Cyber-Physical Systems.” In: *TIIS* (2014). DOI: [10.3837/tiis.0000.00.000](https://doi.org/10.3837/tiis.0000.00.000).
- [3] B. Kitchenham. *Guidelines for performing Systematic Literature Reviews in Software Engineering*. Tech. rep. EBSE 2007-001. Keele University and Durham University Joint Report, July 2007.
- [4] B. A. Kitchenham, H. Al-Khilidar, M. A. Babar, M. Berry, K. Cox, J. Keung, F. Kurniawati, M. Staples, H. Zhang, and L. Zhu. “Evaluating guidelines for reporting empirical software engineering studies.” In: *Empirical Software Engineering* 13.1 (2008), pp. 97–121.
- [5] H. Koziolk. “Sustainability Evaluation of Software Architectures: A Systematic Review.” In: *Proceedings of the Joint ACM SIGSOFT Conference – QoSA and ACM SIGSOFT Symposium – ISARCS on Quality of Software Architectures – QoSA and Architecting Critical Systems – ISARCS. QoSA-ISARCS ’11*. New York, NY, USA: ACM, 2011, pp. 3–12. ISBN: 978-1-4503-0724-6. DOI: [10.1145/2000259.2000263](https://doi.org/10.1145/2000259.2000263). URL: <http://doi.acm.org/10.1145/2000259.2000263>.
- [6] Y. Z. Lun, A. D’Innocenzo, I. Malavolta, and M. D. Di Benedetto. “Cyber-Physical Systems Security: a Systematic Mapping Study.” In: (2016), pp. 1–32. URL: <http://arxiv.org/abs/1605.09641>.
- [7] F. A. Moghaddam, P. Lago, and P. Grosso. “Energy-Efficient Networking Solutions in Cloud-Based Environments.” In: *ACM Computing Surveys* 47.4 (May 2015), pp. 1–32. ISSN: 03600300. DOI: [10.1145/2764464](https://doi.org/10.1145/2764464). URL: <http://dl.acm.org/citation.cfm?doid=2775083.2764464>.
- [8] B. Penzenstadler, V. Bauer, C. Calero, and X. Franch. “Sustainability in software engineering: A systematic literature review.” In: (2012).
- [9] B. Penzenstadler, A. Raturi, D. Richardson, C. Calero, H. Femmer, and X. Franch. “Systematic Mapping Study on Software Engineering for Sustainability (SE4S).” In: (2014). DOI: [10.1145/2601248.2601256](https://doi.org/10.1145/2601248.2601256).

