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A Socio-Technical Analysis of Challenges in Managing Multi-Clouds

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Abstract. Today's cloud market consists of numerous providers competing and offering new services and features on an almost daily basis. From an organization's perspective, it can therefore be beneficial to consider multiple providers in their cloud strategy to exploit possibilities for differentiation and specialization, ensure service availability, or realize cost savings. However, the resulting multi-cloud environment becomes highly complex and difficult to manage, which leads organizations to hold back from an implementation. Specifically, there is no common ground on what challenges organizations need to address when managing a multi-cloud environment. In this study, we derive a taxonomy of multi-cloud management challenges deductively through a structured literature review and inductively through an analysis of common multi-cloud broker and expert knowledge. Our taxonomy provides organizations with a holistic overview of challenges in managing multi-clouds and is intended to help initiate new interdisciplinary research in the scientific community.

Keywords: Cloud computing, multi-cloud computing, multi-cloud management, multi-cloud challenges

1 Introduction

Since its emergence around a decade ago, cloud computing has become a major economic force [1]. By leveraging economies of scale and providing highly standardized IT-services, cloud computing fundamentally shifted the provision of IT-resources making computing power a utility [2, 3]. The consequences were dramatically lower IT barriers for organizations and service providers, which enable the creation of new business models and IT service value networks [4].

When organizations adopt a cloud strategy, it can be beneficial to consider more than one cloud service provider (CSP) for several reasons. According to Bouguettaya et al. [5] and KPMG [6] using several CSP is the only way to ensure service availability and business continuity in case of CSP outages. The multi-cloud acts hereby as an enabler for distributing workloads and increasing redundancy. Additionally, the cloud computing market is becoming increasingly competitive and CSP are differentiating themselves by specializing for certain functionalities [6, 7] or through attractively low prices [8]. Furthermore, regulatory compliance, performance requirements, or security restrictions are driving forces behind multi-cloud strategies [9].

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However, a survey among organizations found out that so far only 35% are leveraging the opportunities of a multi-cloud environment [6]. The respondents mentioned that the major factors hindering an adoption are the complex planning and management of multi-cloud environments. Following this, a multi-cloud raises several new challenges that organizations are facing nowadays [6, 10]. In literature, these challenges are often discussed on a technically detailed level with a focus on a specific challenge (e.g., [11, 12]). An up-to-date, comprehensive, and interdisciplinary overview of challenges that organizations face when managing multi-clouds is, to the best of our knowledge, currently not available. It would, however, help organizations to plan and manage a multi-cloud environment and lower the barriers for adopting a multi-cloud. Furthermore, such an overview would provide researchers a common basis for structuring multi-cloud challenges and provide avenues for future research. To address this research gap, we formulated the following research question:

Research Question: What are the main challenges in managing multi-clouds?

To answer the proposed research question, we decided to create a taxonomy of multi-cloud management challenges. A taxonomy is a well-suited form for formalizing our findings as it allows a structured organization of knowledge in a given field [13]. To create the taxonomy, we followed the structured development process introduced by Nickerson et al., which combines iterative inductive and deductive development steps over relevant literature and objects in the target field [13].

The remainder of this paper is structured as follows: In section two we present the research background of our work. We continue by describing the taxonomy development process in section three. In section four we present our developed taxonomy of multi-cloud management challenges and conclude with contributions and limitations of our findings in section five.

2 Background & Related Work

2.1 Cloud Computing Models

Cloud computing refers to the on-demand delivery of computing resources as a service and originated over a decade ago. Several definitions of cloud computing appeared in the scientific literature, but the definition by the National Institute of Standards and Technology (NIST) [14] is the most common and widely accepted. They define cloud computing as "… a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [14]. Since its inception the cloud computing paradigm quickly evolved to address arising challenges such as security issues, legislative requirements, vendor lock-ins, or incompatibility. As a result, more advanced cloud computing models, such as multi-clouds, emerged and represent the next step in the evolution of cloud computing [15].

Multi-cloud computing refers to the use of multiple cloud computing services from more than one public or private CSP (e.g., Microsoft Azure, Amazon Web Services, or Google Cloud Platform) [16, 17]. In comparison, a hybrid cloud refers to the combined use of a public and a private cloud deployment model or a public cloud combined with on-premise IT infrastructure, regardless of how many CSP are involved [18]. Federated and inter-cloud computing models usually specify a scenario in which multiple CSP are sharing resources. Especially for small CSP this offers the opportunity to share intensive workloads and extend their own service offerings.

In this study, we focus on challenges in managing multi-clouds from an organization's perspective, that acts as a cloud user. To maintain our focus, we disregarded challenges that CSP face in the managing and provisioning of multi-cloud solutions. Furthermore, it is not the intent of this paper to define challenges organizations face in managing a single cloud, nor to define on-premise to cloud transition challenges. Nevertheless, it is important to mention that single-cloud and multi-cloud challenges do overlap in many aspects and could both influence the decision process of going to the cloud. However, we argue that there are concrete multi-cloud management challenges that go beyond the challenges in a single cloud environment. For example, security is an important challenge in both a single-cloud and a multi-cloud environment, but in our study we focus on security challenges organizations are facing when managing multi-clouds in particular, like the expanded attack surface that originate from handling multiple public CSPs simultaneously.

2.2 Multi-Cloud Taxonomies

Despite the importance of multi-cloud computing for enterprises and the accelerating adoption rates, the existing literature on multi-clouds is concentrated on individual aspects of multi-clouds [15, 18]. For instance, there are several studies, which examine security challenges in multi-clouds (e.g., [19, 20]) or discuss solutions for orchestrating multi-clouds (e.g., [21, 22]). The current body of literature lacks a systematic and interdisciplinary overview of the challenges organizations face when adopting a multi-cloud architecture [15]. They are, therefore, not able to provide a practically oriented guideline that IT managers can incorporate into their decision-making processes. This study aims to close this research gap by providing a multi-cloud challenges taxonomy to support organizations in managing their multi-cloud environment.

To the best of our knowledge such a taxonomy does not exist yet. The two papers from Grozev and Buyya [23] and Toosi et al. [10] are coming closest to our idea of a multi-cloud challenges taxonomy. In contrast to other papers, both papers do not consider only particular challenges but aim to provide a more holistic overview. We, therefore, argue that their findings can inform our work and we consider the two papers the most beneficial to our study. Both studies are providing consistent and well-defined taxonomies. Nevertheless, we would like to highlight a few crucial points that demonstrate the need for an up-to-date and holistic taxonomy of challenges in managing multi-clouds. Although many of the challenges from the two above mentioned papers are applicable to multi-cloud environments, these papers still focus on inter-cloud challenges. As mentioned before, the main aspect of a multi-cloud is the use of multiple cloud computing services from more than one CSP and not the sharing of resources between multiple CSP as it is the case with an inter-cloud environment. That said, there are of course many overlapping aspects with these two, but also additional challenges specifically related to multi-clouds that need to be considered in a multi-cloud challenges taxonomy. In addition, both papers mentioned above have a more technological approach, as they originate from the software engineering and computer science communities. A holistic taxonomy requires a more detailed inclusion of socio-technical challenges in managing multi-clouds. Finally, as the cloud environment has evolved significantly over the last few years, we see the need to at least look out for new challenges that emerged in the past seven years, since both papers were published in 2014.

3 Taxonomy Development Process

The following chapter presents a detailed description of the *taxonomy development process* according to Nickerson et al. [13]. For this purpose, the following seven steps, some of which are sequential and some of which are repetitive, are performed: First, the meta-characteristics of the taxonomy are determined by defining the purpose of the taxonomy and the expected usage by the user. In the second step, the ending conditions of the taxonomy development process are defined. In steps three to six, a distinction is made between two different approaches. In the conceptual-to-empirical approach, the literature is used as a source to determine the dimensions and characteristics of the taxonomy. In the empirical-to-conceptual approach, dimensions and characteristics are derived empirically, for example using insights from experts in the field. In the seventh step, the derived findings are tested against the ending conditions. Steps three to six are then repeated until all ending conditions are met.

3.1 Meta-Characteristic & -Dimensions

The *meta-characteristic* defines the purpose of the taxonomy, which in turn is correlated to the expected benefit of the taxonomy for the user. In our case, the purpose of the taxonomy is to provide organizations with a comprehensive overview of the most important challenges in managing multi-clouds. As a result, we define "multi-cloud challenges" as the meta-characteristic of this taxonomy.

Regarding the development of *meta-dimensions* in the context of multi-cloud computing, both literature and practical examples show different approaches. Brogi et al. [24], for example, cluster their multi-cloud management platform on a meta-dimension level using a temporal approach. Other multi-cloud papers focus on a specific subject area, such as monitoring [25], resource management [26] or security [19, 27]. Thus, no comprehensive view of multi-cloud challenges is given, and a meta-dimension is not used. However, also papers such as the one by Toosi et al. [10] or Masdari and Zangakani [28], which in contrast to the previously mentioned papers establish a more comprehensive taxonomy, refrain from creating meta-dimensions.

Nevertheless, as part of our taxonomy development process, we decided to set up meta-dimensions to increase the transparency and usability of the taxonomy.

To create the meta-dimensions, we use the *technology-organization-environment (TOE) framework*. The TOE framework was originally developed by Tornatzky and Fleischer [29] to describe the influence of various factors regarding the decision of organizations to adopt new technologies. Nowadays, the TOE framework is used in a variety of areas due to its ease of use and explanatory power. It is also a proven tool in the context of cloud computing [30–36]. The resulting three meta-dimensions can be described as follows: The *technological* meta-dimension encompasses all technological challenges that arise when managing a multi-cloud environment. The *organizational* meta-dimension covers all management challenges that emerge within the company on an organizational level and the meta-dimension *environmental* covers all external management challenges affecting an organization.

3.2 Ending Conditions

The second step is to specify the *ending conditions* that will be used to develop the taxonomy [13]. The ending conditions determine the number of iterations to be performed, since all ending conditions must be fulfilled after the last iteration. The following table indicates the fulfillment of the ending conditions depending on the iterations performed in the following sections.

Table 1. Ending conditions (leaned on Nickerson et al. [13])

	Ending Conditions	**1**	**2**	**3**	**4**
Objective	All objects or a representative sample of objects have been examined	-	-	✓	✓
	No object was merged with a similar object or split into multiple objects in the last iteration	-	-	-	✓
	At least one object is classified for every char. of every dimension	✓	✓	✓	✓
	No new dimensions or characteristics were added in the last iteration	-	-	-	✓
	No dimensions or characteristics were merged or split in the last iteration	-	-	-	✓
	Every dimension is unique and not repeated	✓	✓	✓	✓
	Every characteristic is unique within its dimension	✓	✓	✓	✓
	Each cell (combination of characteristics) is unique and is not repeated	✓	✓	✓	✓
Subjective	Concise	-	✓	✓	✓
	Robust	-	-	✓	✓
	Comprehensive	-	-	✓	✓
	Extendible	-	✓	✓	✓
	Explanatory	-	✓	✓	✓

3.3 Conceptual to Empirical Approach

To lay the foundation of the taxonomy, we start with a structured literature review (SLR) following the methodological approach of vom Brocke [37] and Webster and

Watson [38]. The SLR is conducted on the databases Scopus, AiSel, IEEE and ACM. To find all relevant papers, the search string shown below is used, which combines relevant keywords:

("Multi-Cloud" OR "Inter-Cloud" OR "Multiple Cloud" OR "Multicloud" OR "Interconnected Cloud") **AND** ("taxonomy" OR "framework" OR "reference model" OR "architecture" OR "Ontology" OR "Strategy" OR "Challenges")

The first review (title-abstract-keyword) resulted in a total of 3041 papers, which is why the search radius was narrowed down to the article title. This led to a total of 266 results. Subsequently, systematic screening was used to eliminate all papers with a different thematic focus, as well as all duplicates and papers that were not written in English. The remaining 74 papers form the scientific foundation of the taxonomy. In addition, there are seven papers that were identified in the course of the for- & backward search [38].

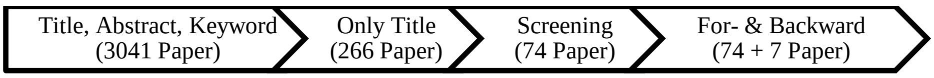

Figure 1. Systematic literature review process

The analysis of these 84 papers within the *first iteration* led to a total of nine dimensions with 30 characteristics. In the context of the SLR, it is mentionable that most of the reviewed papers had a technological focus, which is why the meta-dimension *technological* was significantly shaped by the first iteration. Specifically, the five technological dimensions *Orchestration* [19, 21, 22, 39], *Portability* [40], *Data* [41, 42], *Operations* [43–45], and *Security* [20, 27, 46] were added. In addition, three organizational dimensions have been added in the form of *Monitoring* [10, 12, 25, 47], *Governance* [8, 24] and *Cost* [10, 42, 48], and one environmental dimension in the form of *Market* [10, 26] has been created based on the SLR.

3.4 Empirical to Conceptual Approach

To further improve the taxonomy, we decided to conduct the *second iteration* examining some of the most well-known multi-cloud brokers as part of the empirical-to-conceptual approach. Using the definition according to NIST, a cloud broker "… is an entity that manages the use, performance and delivery of cloud services and negotiates relationships between cloud providers and cloud consumers" [49]. Thus, multi-cloud brokers also deal with challenges in managing multi-clouds and are therefore well suited for the further development of this taxonomy. To analyze the multi-cloud brokers, we took an in-depth look at the multi-cloud management platforms of the brokers and their specific functionalities. Furthermore, we scanned additional articles, whitepapers and blog posts related to the brokers and their different solutions. Specifically, the second iteration examined the multi-cloud brokers *IBM Multicloud Management Services, Cloudmore, Jamcracker Cloud Services Brokerage* and *Boomi* as they were, among others, awarded as best cloud brokers in 2021 [50]. The analysis of the brokers consolidated the taxonomy to seven dimensions with a total of 23 characteristics. In the technological meta-dimension, we summarized the characteristics assigned to the *Data* and *Portability* dimensions under the term of their respective dimension and moved these as new characteristics to the *Orchestration* dimension. We conducted this step, because cloud brokers often mention the respective functionalities under the term orchestration, and it helped our taxonomy to become more concise and robust. We, moreover, moved several characteristics from one dimension to another. Regarding the organizational dimensions, the previously established dimension *Monitoring* has now become part of the dimension *Governance*, as the cloud brokers also tend to subordinate it here. The *Expertise* dimension has been newly added here, as expertise represents a major challenge in managing multi-clouds, which has not been considered in the SLR in the first iteration at all.

The *third* and *fourth iteration* are also performed using the empirical-to-conceptual approach. We conducted two consecutive series of workshops (third and fourth iteration) with four individual workshops in both series, each with one participant. The four participants can be divided into two areas of expertise. Two participants have a primarily technical background and work, among other things, on the implementation, orchestration and deployment of cloud and multi-cloud environments. The other two participants have a more economical background and therefore primarily work on organizational cloud and multi-cloud issues as well as topics related to the cloud market. The starting point for each workshop was given by the taxonomy draft after the second iteration. In the third iteration we made only minor changes in the technological meta-dimension. Specifically, we renamed several characteristics to become more comprehensive and understandable. For example, we changed the characteristic *Lack of Interoperability* to *Compatibility* as this was more concise and better represented the knowledge we gained. Regarding the organizational dimensions, for example, *Execution* with its characteristics *Selection* and *Provisioning* has been created as a completely new dimension to emphasize management challenges in the execution of multi-clouds in an organization. Thus, after the third iteration, the taxonomy is composed of a total of seven dimensions and 17 characteristics. The subsequent workshops series as part of the fourth iteration with the same four participants did not result in any further changes within the taxonomy and all ending conditions were met.

4 Multi-Cloud Challenges Taxonomy

In this chapter, the final taxonomy of challenges in managing multi-clouds is presented. For this purpose, the *meta-dimensions* **(MD_n)**, the associated *dimensions* **(D_{nm})** and the *characteristics* **(C_{nmk})** assigned to the dimensions are described in detail below. Organizations may face multiple challenges in managing multi-clouds shown in the different characteristics in each dimension, which means that all dimensions of the taxonomy are non-mutually exclusive. In addition, the characteristics are intentionally generalized so that one characteristic may contain multiple challenges associated to that characteristic. The specific challenges of each characteristic are described in detail throughout this chapter.

Table 4. Final taxonomy after the 4th iteration

<table>
<tr><th>Meta-Dimension (MD_n)</th><th>Dimension (D_{nm})</th><th colspan="6">Characteristics (C_{nmk})</th></tr>
<tr><td rowspan="3">Technological</td><td>Security</td><td colspan="2">Architectures</td><td colspan="2">Risk assessment</td><td colspan="2">IAM</td></tr>
<tr><td>Orchestration</td><td colspan="2">Compatibility</td><td colspan="2">Portability</td><td colspan="2">Data</td></tr>
<tr><td>Operations</td><td colspan="2">Deployment</td><td colspan="2">Configuration</td><td colspan="2">Reliability</td></tr>
<tr><td rowspan="3">Organizational</td><td>Governance</td><td colspan="3">Monitoring</td><td colspan="3">Cost Control</td></tr>
<tr><td>Execution</td><td colspan="3">Selection</td><td colspan="3">Provisioning</td></tr>
<tr><td>Personal</td><td colspan="3">Expertise</td><td colspan="3">Change</td></tr>
<tr><td>Environmental</td><td>Market</td><td colspan="3">Offerings</td><td colspan="3">Compliance</td></tr>
</table>

4.1 Meta-Dimension: Technological

The meta-dimension *Technological* **(MD_1)** summarizes technological challenges that organizations face in managing multi-clouds. As said before, we hereby focus on the challenges and potential solutions specific for managing multi-clouds from an organization's perspective.

The dimension *Security* **(D_{11})** describes challenges that are associated with securing a multi-cloud. Hereby, the main challenges are the growing complexity and the expanded attack surface that originate from handling multiple public CSPs. Specifically, an organization needs to handle heterogeneous security *Architectures* **(C_{111})** of different CSP, which include handling different security policies, frameworks, and implementations. Following Afolaranmi et al. [20], the number of interfaces and endpoints increases with the number of CSP and causes the security architecture to become more error prone and vulnerable. It is, thus, important to ensure transparency and use proxies or intermediary systems to overcome this issue and prevent harmful acts [20]. Additionally, to meet the expanded attack surface by multiple CSP, organizations need a comprehensive *Risk Assessment* **(C_{112})**. To mitigate these risks and achieve a high level of security they are required to conduct a threat identification, risk analysis, and calculate relevant security metrics [20, 27, 46]. Along with the heterogeneity, organizations also face challenges regarding the *Identity and Access Management (IAM)* **(C_{113})**. Multiple CSP require multiple logins and security credentials. An inconsistent management of these poses a great security risk (e.g., through illicit data access). In [27] the authors propose the usage of centralized security services with consistent access control and security management covering all architectural parts of an application. This way the centralized security service can enable the federation of distributed multi-cloud resources using the individual cloud access credentials over a single point [27].

In the dimension *Orchestration* **(D_{12})** we summarize challenges that originate from different technological stacks and standards among multiple CSP. These require an orchestration of distributed cloud offerings as part of integrated processes across multiple clouds. An important challenge in this dimension is the lack of *Compatibility*

(C_{121}) among cloud resources. If cloud solutions lack the necessary interoperability, users are likely to experience a vendor lock-in [39]. In literature, several approaches try to address this challenge with a centralized interface or service (e.g., [21, 22, 39]). Following Tomarchio et al., the additional level of abstraction “hides differences and avoids the need for provider-specific customization” [22]. Furthermore, a standardized, independent, and interoperable description of application topologies could support the reusability and help to leverage the benefits offered by multi-clouds. The Topology and Orchestration Specification for Cloud Applications (TOSCA) [51] is such an open standard, which is well-established and offers a specification for the vendor independent description of applications. Closely related to interoperability is the *Portability* **(C_{122})** of applications. Portability refers to the ability to ‘lift-and-shift’ complete solutions from one cloud infrastructure to another. It is defined as the capability to execute a program on various systems without major conversions [40]. It consists of three components: data, application, and service or platform portability [22]. Hereby, container-based virtualization is a key concept for isolating different parts of an application and providing a common way of description. *Docker* is the leading solution for container-based virtualization. If a large number of containers is used, it can be extended with orchestration tools at the container level such as *Kubernetes*. Furthermore, another challenge is the orchestration of *Data* **(C_{123})** over multiple clouds. Specifically, the complexity to keep data updated across several vendors and integrate processes within a multi-cloud is getting more difficult [42]. Thus, organizations need to develop strategies addressing data replication and data consistency [41]. These strategies must incorporate the different aspects relevant to cloud data management, like costs, performance needs or number of data accesses.

The dimension *Operations* **(D_{13})** specifies challenges that arise in managing different cloud infrastructures for deployment that the user has limited control over. An important challenge in this dimension is the *Deployment* **(C_{131})** of applications. Each CSP has its own service (e.g. Azure Resource Manager) and specialized workflows for application deployment [43, 44]. These make it difficult to manage multiple deployments in different environments. The problem can be overcome using intermediary cloud broker or dedicated deployment solutions, like *Jenkins*. The second operative challenge is the *Configuration* **(C_{132})** of the infrastructure required for deployment. This characteristic describes the configuration and expected status of the CSP infrastructures needed in a multi-cloud scenario [43]. The tool *Ansible* is a widely established solution that addresses this challenge. Finally, a multi-cloud infrastructure can introduce new *Reliability* **(C_{133})** issues when all cloud instances are required for a frictionless operation. Hereby, using services of multiple datacenters increases the risk for possible outages or downtimes [45].

4.2 Meta-Dimension: Organizational

The meta-dimension *Organizational* **(MD_2)** lists all organizational multi-cloud management challenges that need to be considered when implementing and running multi-clouds.

The *Governance* **(D_{21})** dimension addresses organizational challenges that arise when it comes to an efficient and comprehensible use and control of cloud services. The four iterations of the taxonomy have shown that different authors and experts classify cloud-governance into different characteristics. As part of the organizational meta-dimension, we focus on the two characteristics monitoring and cost control. Other cloud-governance-related characteristics such as IAM or compliance are discussed in the other meta-dimensions of this taxonomy. *Monitoring* **(C_{211})** in the cloud is a broad term that generally describes the monitoring of various cloud services and resources and their performance [10]. The challenges of monitoring multi-cloud environments primarily come from the diversity and lack of interoperability of the various monitoring tools offered by the CSP [25], which lead to a lack of transparency and control and ultimately result into cloud sprawl [52]. To overcome the challenges, it can be useful to consider third-party tools in order to obtain a unified overview of the organization's cloud usage [53]. Well-known examples of third-party tools which combine monitoring data from different environments are *Datadog* or *Splunk*. Managing multi-clouds also creates challenges regarding *Cost Control* **(C_{212})** that organizations need to consider. Starting with a more difficult allocation of costs for resources used in the organization, all the way to a high complexity regarding the different charging and billing methods used by the CSP, a wide range of cost control challenges arise [54]. Therefore underutilization (paying for unused cloud services) is a common risk that occurs, if organizations do not address cost-related challenges when managing multi-clouds [55]. In addition to a stringent naming and tagging of resources across all CSPs, it can be useful to again consider third-party tools from companies such as Flexera with *Flexera One* or VMware with *CloudHealth*, to overcome these challenges.

The *Execution* dimension **(D_{22})** addresses challenges that organizations face when selecting and provisioning cloud services from different CSP. The *Selection* **(C_{221})** of the right CSP and services are central challenges when managing multi-clouds. Services are generally selected based on a trade-off between cost and performance parameters [26]. The challenge is to achieve the best possible compromise between cost and performance when selecting services from different CSP. Regarding the cost parameters, cloud cost comparison solutions from multi-cloud brokers can be used to create an immediate cost comparison of different CSP offerings. However, these still must be set in relation to performance parameters such as response time or availability. This leads to another challenge in the context of this characteristic, which is a sufficient automation of the process. This is where self-service tools come in handy, providing managers with a central place to compare and select cloud-based services [54]. Furthermore, environmental factors also play an important role in selecting the right CSP. These will be discussed in the next meta-dimension. *Provisioning* **(C_{222})** refers to the provisioning of cloud services from an organization or an organization's IT department to their internal cloud-users. The challenge here is to provide users with cloud services from different CSPs with as little complexity as possible through standardization and a unified interface. This challenge can also be handled by the aforementioned self-service tools, which allow IT professionals to manage usage and provisioning of the cloud services in a standardized and unified way [54]. Multi-cloud brokers such as *jamcracker* go even further by offering a cloud services brokerage solution that allows organizations to act as a multi-cloud broker themselves [56].

The *Personal* dimension **(D_{23})** addresses challenges related to the expertise required to manage multi-clouds and the associated changes within the organization. Having the necessary *Expertise* **(C_{231})** or, in other words, the right skillset to effectively manage the various offerings of the CSP is a big challenge in multi-cloud computing [57]. IT teams and managers need to be well-versed in working across multiple clouds and most of the time, they will need specialized knowledge and experience with all the CSPs the organization is using [58]. The challenge for organizations is therefore both the hiring of new, qualified personnel as well as the systematic training of existing personnel. As organizations move to a multi-cloud environment and employees gain a new set of cloud-related IT skills, this inevitably leads to *Change* **(C_{232})** in terms of many traditional IT roles within the organization. The IT department becomes more of a supply chain operator, architects become service authors and Chief Information Officers (CIOs) become contract and procurement experts, who manage the vendor and supply chain [54]. Thus, the challenge for organizations is to manage these changes both inside and outside their IT.

4.3 Meta-Dimension: Environmental

The meta-dimension *Environmental* **(MD_3)** identifies multi-cloud management challenges that arise from the surrounding environment.

When managing multi-clouds, it is of great importance to know the current cloud *Market* **(D_{31})** and the challenges it creates for an organization. It is important to mention that challenges identified in this dimension also exist in a single-cloud environment but have a higher significance in the context of multi-clouds, which is why they are explicitly listed in our taxonomy. These challenges can be divided into the following two characteristics. The *Offerings* **(C_{311})** of cloud services is enormous. Today, there are more than 800 CSP offering a public cloud [59]. The three Hyperscaler Microsoft Azure, Amazon Web Services and Google Cloud Platform alone offer a total of more than 600 individual services and significantly more services from third-party providers via their marketplaces. The challenges for organizations are therefore not only to know and understand the various services offered by the CSP, but also to constantly stay up to date when new services appear or when the parameters of existing services change. This challenge is particularly demanding in a multi-cloud environment, as changes and new developments must be considered from all the CSPs used in the multi-cloud. In this context, IBM speaks of a dynamic, up-to-date self-service store for organizations, in which changes are managed "behind the scenes" in order to meet these challenges [54]. *Compliance* **(C_{312})** is another important challenge especially in the context of multi-clouds. Organizations often have to meet multiple internal and external compliance requirements as part of their cloud transformation [58]. The challenge for organizations is therefore to create a multi-cloud environment in which different CSP are chosen in a targeted manner to meet external compliance requirements such as the *General Data Protection Regulation* (GDPR).

5 Contributions & Limitations

By developing a taxonomy of challenges in managing multi-clouds, the paper provides both, scientific contributions for theory and research, as well as managerial contributions for multi-cloud users and organizations interested in multi-cloud computing.

Regarding *scientific contributions*, our study extends the existing body of literature by offering a comprehensive analysis of the challenges that arise when managing multi-clouds. With respect to the two papers that were closest to the idea of our paper [10, 23], we were able to produce what we believe to be a more holistic outcome by using a socio-technically driven approach. We, therefore, combined empirical and theoretical sources for reasoning to create a taxonomy that is profound and state-of-the-art. This way, we provide researchers with an interdisciplinary insight into the field of challenges in managing multi-clouds, which was not available beforehand. Additionally, by creating a common basis for systematizing multi-cloud challenges, our taxonomy can spark new research to address the identified challenges in a more detailed manner. Specifically, our taxonomy serves as an interdisciplinary tool to structure existing solutions that address multi-cloud challenges and derive potential research gaps or inform the creation of new solutions. We hope that our study will lead to the interdisciplinary research that is necessary to overcome these challenges and help organizations in leveraging the full potential of multi-clouds.

In terms of *managerial contributions,* the paper addresses both, organizations that are planning to use multi-cloud computing in the future and those that are already actively using multi-clouds. For the former, the taxonomy provides a good overview of the challenges that especially corporate IT managers need to address to establish successful multi-clouds. For organizations that already manage multi-clouds, the taxonomy can be used as a checklist to identify which challenges they have already encountered or overcome, and which ones still need to be considered in the future. Especially within the managerial contributions, we see the TOE framework as a suitable tool to get a comprehensive, yet understandable overview of challenges in managing multi-clouds. It enables organizations to preventively avoid mistakes when managing their multi-cloud environment. Furthermore, the taxonomy can also be used as an instrument for selecting a suitable multi-cloud broker, as multi-cloud brokers should also address most of the challenges identified.

Ultimately, this paper is also subject to *limitations*. The first iteration within the taxonomy development process was conducted using a structured literature review. We conducted the SLR to the best of our knowledge and tried to present the whole process as transparently as possible. Nevertheless, it is still possible that not all relevant papers could be identified during the SLR. Furthermore, we have tried to remain as objective as possible throughout the whole development of the paper. However, a certain subjective influence cannot be completely excluded, especially during the third and fourth iteration of the taxonomy, which were based on the expert workshops. Ultimately, the question of the completeness of the taxonomy cannot be answered with complete certainty. Therefore, we hope that the way we build the taxonomy will encourage other researchers to further develop it in the future.

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