

**QUESO A QUALITY MODEL FOR OPEN
SOURCE SOFTWARE ECOSYSTEMS: LIST OF
MEASURES**

*Oscar Franco-Bedoya, David Ameller, Dolors Costal and
Xavier Franch.*

Abril, 2016

UPC University

Software and Service Engineering Group (GESSI)

Technical Report No. ESSI-TR-16-1

**Universitat Politècnica
de Catalunya
Barcelona, Spain**

Summary

This technical report is part of QuESo-V2.0 a quality model for open source software ecosystems (OSSECOs). Our prior efforts have focused on providing a detailed list of the quality measures found during the execution of a systematic mapping on OSSECOs. In this new version of the model, we addressing some of the issues that were highlighted in the QuESo V1.0 such as: the unbalanced distribution of measures and the ambiguity of some measures names. The measures listed in this report are not intended to be an exhaustive and complete set. However, this list provides a representative collection of OSSECOs measures. It is a small step in the direction of developing a platform for support the analysis of OSSECO.

Contents

1	Introduction	1
2	QuESo Model	1
3	QuESo Measures	3

List of Figures

1	QuESo quality model	2
2	QuESo-measure ontology	4

List of Tables

1	Size measures.	6
2	Activeness measures	7
3	Heterogeneity measures.	9
4	Regeneration ability measures.	10
5	Effort balance measures.	11
6	Expertise balance measures.	12
7	Visibility measures	13
8	Community cohesion measures.	15
9	Ecosystem cohesion measures.	16
10	Information consistency measures.	17
11	Synergetic evolution measures.	18
12	Interrelatedness ability measures.	19
13	Niche creation measures.	20
14	OSSECO Knowledge measures.	21
15	Visibility measures	21
16	Trustworthiness measures.	23

1 Introduction

This technical report provides a detailed description of the measures defined in QuESo V2.0. The measures listed in this technical report were obtained from a systematic mapping of open source software ecosystems (OSSECOs). These are grouped in four quality characteristics defined in QuESo V2.0 (i.e., *productivity*, *sustainability*, *network health* and *resources health*). They are defined for measuring the quality of OSSECOs. However, researchers, OSS communities, developers, OSS adopters, and those related to OSSECOs may use these measures for adapting their own approaches.

QuESo V2.0 is a quality model for OSSECOs that defines quality characteristics, subcharacteristics and measures. The quality characteristics in QuESo V2.0 have been organized in three dimensions: (1) those that relate to the platform around which the ecosystem is built, (2) those that relate to the community (or set of communities) of the ecosystem and (3) those that are related to the ecosystem as a network of interrelated elements, such as partners or companies (see Fig. 1). Furthermore, QuESo describe how any of these subcharacteristics could be measured using statistical inference and experts' knowledge.

We recommended to use this technical report together with the QuESo-V2.0 model, particularly if it will be used to assess the quality of an OSSECO.

2 QuESo Model

According to ISO 25010 standard, the quality of a system (e.g., OSSECO) is the degree to which the OSSECO satisfies the stated and implied needs of its various stakeholders [16]. Those stakeholders' needs are precisely what is represented in the quality model, which categorizes the OSSECO quality into characteristics and sub-characteristics. Fig. 1 shows the QuESo-V2.0 quality model.

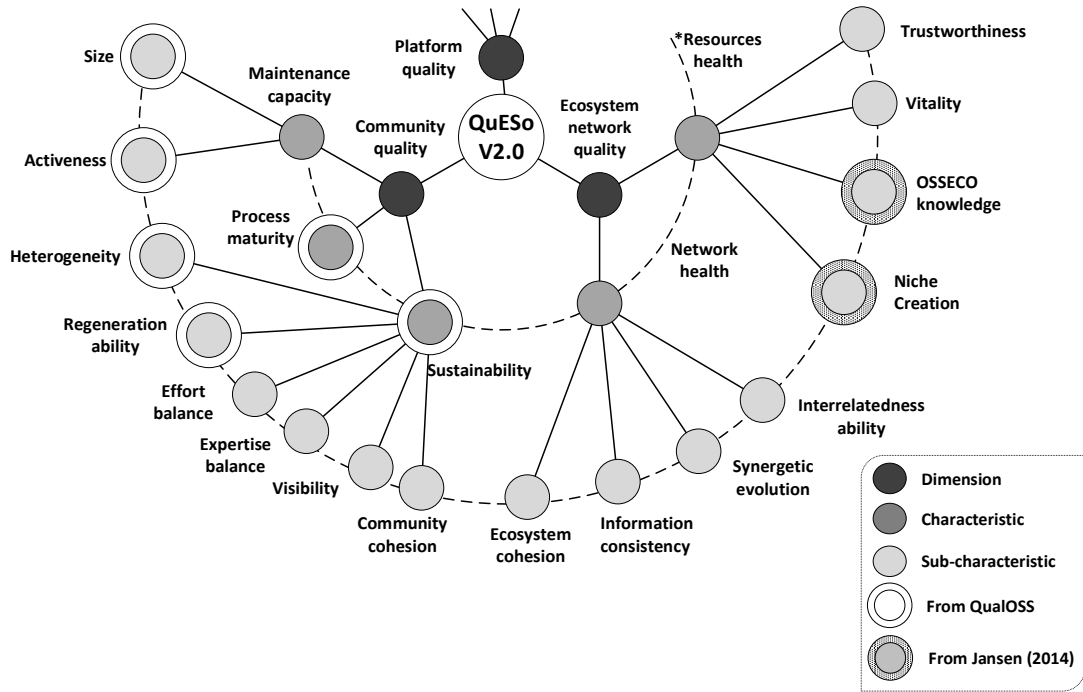


Figure 1: QuESo quality model

In the next subsections, we describe each of the quality characteristics of QuESo-V2.0.

2.1 Maintenance capacity

OSSECOs need a continuous input of energy in the form of new development or maintenance of the ecosystem. It is the capacity of a OSSECO to provide the resources necessary for maintaining its products [32]. In OSSECOs the maintenance capacity balances the OSS community practices and the needs of the other members of the OSSECO. In general the objective of the maintenance capacity is allowing the modification of the existing OSSECO resources, relationships and products while preserving its integrity.

2.2 Process maturity

From an OSSECO approach the software development process cannot be subjected to standardized process models, tools and ways of working. This means that traditional process maturity approaches, such as CMMi become much more difficult to apply in this context [13, 35]. However, determine which good practices a specific OSSECO follows, as well as how established these practices are, is perfectly reasonable. Soto and Ciolkowski define OSSECO process maturity as the ability of a OSSECO to consistently achieve development-related goals by following established processes. It

can be assessed for specific software development tasks with the answers of questions such as: (1) is there a documented process for the task?, (2) if there is an established process, is it executed consistently? [32]. We omit process maturity of our model because we have not found quantitative measures to evaluate it. Furthermore, [32] developed a process maturity evaluation framework specifically aimed at OSSECOs.

2.3 Sustainability

According to [6] sustainability is one of the fundamental challenges in any type of ecosystem. A sustainable natural ecosystem maintains its characteristic diversity of major functional groups, productivity, and rates of bio-geochemical cycling, even in the face of disturbing events. Similar to Dhungana et al.[6], we defined a sustainable OSSECO to be the one that can increase or maintain its products, resources, members and relationships over longer periods of time and can survive inherent changes such as new technologies, new products, competitors that can change the population. In summary sustainability is the likelihood that a OSSECO remains able to maintain the products or services it develops over an extended period of time.

2.4 Network health

Hartigh et al. define network health as a representation of how well partners are connected in the ecosystem and the impact that each partner has in its local network [5]. Healthy ecosystems show many relations and subsystems of different types of elements that are intensely related [10]. Furthermore, in a healthy OSSECO network, these relations are mutualistic [26]. Van der Linden et al. proposed to evaluate the network health of an OSSECO before its adoption [33].

2.5 Resources health

In business ecosystems (BECOs), resources health is related to the financial health concept defined by Hartigh et al. [5]: “it is a long-term financially based reflection of a partner’s strength of management and of its competences to exploit opportunities that arise within the ecosystem and is directly related to the capability of an ecosystem to face and survive disruption”. In the context of OSSECOs, we defined resources health as the ability of an OSSECO to obtain value from their symbiotic relationships between all members and resources of the ecosystem. This means that the OSSECO will remain growing and increasing in longevity [17].

3 QuESo Measures

In this chapter we described the measures used in the QuESo quality model. In order to describe in detail the QuESo measures, we introduce a basic QuESo-measure ontology (see Fig 2). this shows the graphical representation of classes and properties of

the ontology. We are using the visual notation for OWL ontologies language (VOWL) [24].

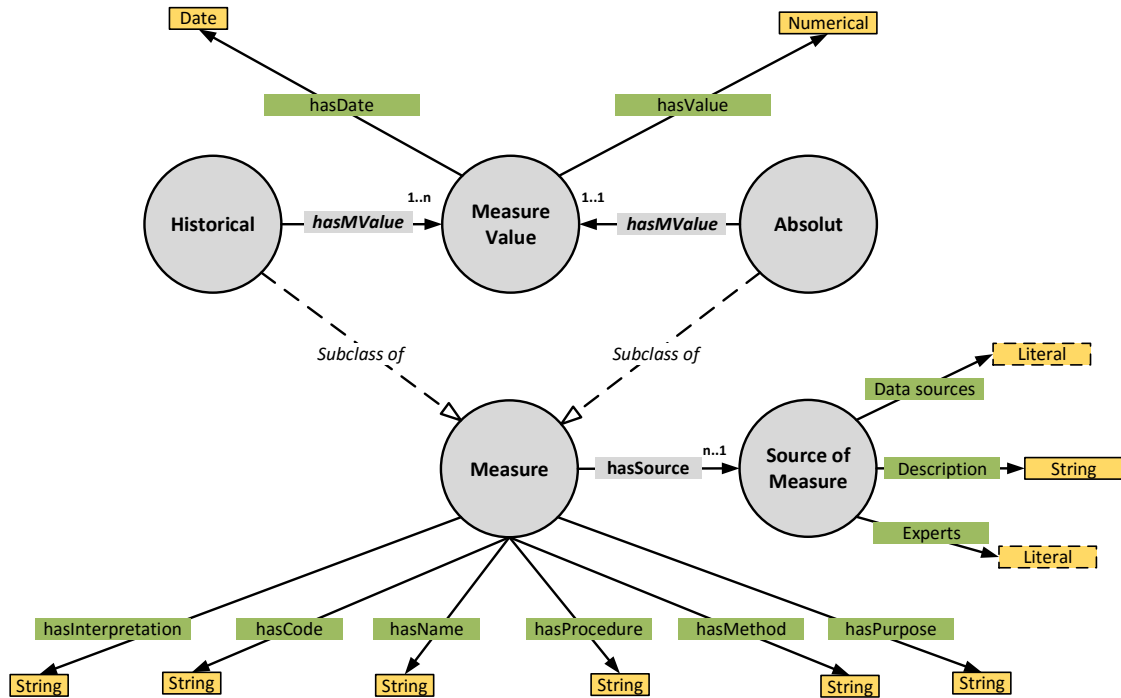


Figure 2: QuESo-measure ontology

3.1 Measure structure

Based on the ontology, the most important concepts in measure-definition are:

Measure This class represents all measures in the QuESo Quality model. The list of datatype properties of this class is:

- *Code*: Unique identifier for the measure.
- *Name*: Name of the measure.
- *Purpose*: It is a question answered by the measure use. What does this metric tell us about the OSSECO?.
- *Method*: Provides a summary of the application
- *Procedure*: Describe the measurement process or formula when is available.
- *Interpretation*: Provides the range and preferred values.

Source of Measure This class specify the data repository used as a source for the OSSECO measures.

- *Data sources*: When the measure data can be accessed automatically using software tools.
- *Experts*: When it is necessary to recollect the measure data from heterogeneous experts (e.g., company adopters, OSS-community members, researchers).
- *Description*: A brief description of the measure data source.

Measure Value It is a tuple with two fields: value of the measure and data when this was measured.

Historical In this measure, the measurement process is done in a time interval. The result is a set of measure values.

Absolute In this measure, the measurement is done in a specific time. The result is a single measure value.

3.2 Measure tables

The measures are listed by QuESo quality characteristics and subcharacteristics.

3.2.1 Maintenance capacity

Size

OSSECOs are dynamic entities in which change is the rule, and during this process they grow in size and complexity. This subcharacteristic indicates the overall evolution of the size population in an OSSECO. Simple measures show the size of an active OSSECO. By calculating these measures for different time windows it is possible to study the community dynamics [10]. Because of this, they are ideal for statistical and network analysis, since a high sample size increases the significance of found results and improves the external validity [21]. Finally, OSSECO measures of size are typically used to compare OSSECOs [17]. Table 1 shows the *Size* measures.

Table 1: Size measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
S-NoP	Number of partners	Are there organizations that can provide different types of support to an OSSECO-community?	Count the number of companies, institutions, research communities, etc. that support the OSSECO-community.	Crawler query	More is better. More partnerships indicate a strong project that is well embedded in the community [17].	Data source: OSSECO websites.	A
S-NoPU	Number of passive users	How many people are just downloading and using the software produced by the OSSECO-Community?	Count the number of OSSECO-community members from mailing list that are not contributors.	Data base query	More is better. Passive users are essential for a sustainable OSSECO-community [22].	Data source: OSSECO repositories.	H
S-NoC	Number of contributors	How many people are collaborating in different types of activities in the OSSECO-community?	Count the number of people that make changes in the OSSECO-community data repositories e.g. authors, active users, committers, readers, translators.	Data base query	More is better. Number of active and mature contributors is a measure that indicates a healthy OSS-community [17].	Data source: OSSECO repositories.	H
S-SoNC	Size of network community	What is the size of the OSSECO-community social network?	Count the number of edges in the network. OSSECO-community social network its a graph were nodes are members and the edges are different type of relationships (e.g., emails, shared commits).	Data base query	More is better. Networks with more nodes and connections are bigger and have a better structure.	Data source : OSSECO repositories.	H
S-NoCM	Number of OSSECO-community members	How many people are in the OSSECO-community?	Count the number of contributors, passive users and partners in the the OSS- community.	$NoCM = (SNoP) \cup (SNoPU) \cup (SNoC)$ $SNoCM = n(X)$	More is better. More members indicate that the OSS-community have a good structure for maintaining its products [27].	Data source: OSSECO repositories.	H

Activeness

Activeness as a QuESo quality subcharacteristic refers to the different activity types of the OSSECO. i.e., how much business is created, how much value is added, and how many new players are joining [19]. Furthermore, the OSSECO contributor community level of activity by aggregating data coming from the analysis of mailing list, forum, and bug tracking system archives, as well as from versioning system logs [32]. Table 2 shows the *Activeness* measures.

Table 2: Activeness measures

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
A-BTA	Bug tracking activity	Is the OSSECO-community active in the bug tracking system?	Count the number of bugs activities (e.g., bugs opened, closed, status changed, bug fix time, etc.) from the project bugs tracker system.	A=Number of bugs reported B=Number of critical bugs reported C=Number of bugs opened D=Number of bugs closed G = Bug fix time E = D/ C F= Number of comments created in the project bug tracker system	Bug tracking activity is an indicator of OSSECO-community activity [29] Any of measures can be used to assess the activity in the OSSECO-community, e.g.: A, B, F= can be used to assess the OSSECO community users activity. E, G= Can be used to assess the OSSECO-community contributors activity. If E is near to 0 is better. B= Might play a vital contribution for members participation in the OSSECO-community activities	Data source: OSSECO bug-tracking system.	H
A-CaBFC	Communication and bug fixing correlation	Is there a correlation between OSSECO developers communication and software quality?	Calculate the number of developers communication in mailing list and the number of bugs fixed in a OSSECO-project.	X=Pearson's correlation coefficient(A,B) A= Set of number of communications B= Set of number of bugs fixed X=1 (Perfect positive correlation) 0<X<1 (Positive correlation) X=0 (No correlation) -1 < X < 0 (Negative correlation) X= -1 (Perfect negative correlation)	Perfect negative correlation is better. There is a significant correlation between communication and quality [1].	Data source: OSSECO mailing lists and bug tracking system.	A
A-DoLC	Date of last commit	How is the OSS-community actuality?	Read the date of the last commit from the version control repository system.	Data base query	More recently is better A OSS-community that has more actuality is more active.	Data source: OSSECO version control repository system.	A
A-VH	Version history	How is the OSS-community evolving?	Calculate the number of major releases per year from the OSS-community web	Crawler query	More is better The number of project releases show the evolution in an OSSECO-community [22]	Data source: OSSECO web sites.	H
A-DoLR	Date of last release	How is the OSSECO-community actuality?	Read the date of the last release from the version control repository system.	Data base query	More recently is better A OSS-community that has more actuality is more active.	Data source: OSSECO version control repository system.	A
A-NoCF	Number of changed files	How is the activity in the OSSECO-community repositories?	Count the number of files changed per commit.	Data base query	More is better High number of files changed implies more OSS-community activity [30] and effort [12] .	Data source: OSSECO version control repository system.	H

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
A-CA	Communication activity	How is the communication between OSSECO-community members?	Read the OSSECO-community communications activity from the e-mail system.	It's possible to do several kinds of calculations with this values. D= Number of responses obtained from a message F= Number of messages from contributors	More is better High communications activities implies a high active OSSECO-community [11].	Data source: OSSECO mailing lists.	H
A-CCA	Community contributor activity	How is the commits activity in the OSSECO-community projects?	Count the number of commits and count the number of contributors from the control repository system.	X= number of commits / number of contributors	High is better Commits activity is an indicator of OSS-community activity [12].	Data source: OSSECO version control repository system.	H
A-CCR	Community commit rate	How long between commits of a OSS-community?	Calculate the average of time between first and last commits dates of all OSSECO-community projects.	$CCR = \frac{\sum_1^n PCT(p_i)}{n}$ PCT= interval commit time for a project n= number of OSSECO community projects	Low is better Smaller rate can be interpreted like a more active OSSECO-community.	Data source: OSSECO version control repository system.	H
A-DP	Decline point	When the values of number of emails starts to decline?	Calculate the date for which the number of contributors is an 80% of the culminating point.	$A.DP = x < max(n)*0,8$ n= number of emails		Data source: OSSECO Mailing lists.	A
A-CP	Culminating point	When the number of emails is maximum in the OSS-community history?	Calculate the date for which the maximum number of emails is found in the OSSECO-community history	$A.CP = max(n)$ n= number of emails		Data source: OSSECO Mailing lists	A
A-OCAP	OSSECO-community activity period	Is it possible to know whether a OSS-community was active all the time or there have been some gaps of inactivity during its lifetime?	Identify the period of time between culminating point and decline point	[A-CP,A-DP]	Large is better A large community activity period is better [8].	Data source: OSSECO Mailing lists.	H
A-CT	Community Timelines	How is the OSSECO-community timeliness?	Calculate the average of time between date of request and date of first response of all projects in the OSSECO-community	$ET = \frac{\sum_1^n TFR(r_i)}{n}$ TFR= time interval for first response to a request i n= number of OSSECO-community request.	Low is better [2].	Data sources: OSSECO mailing lists. version control repository system and bug tracking system.	H
A-NoE	Number of events	How is the social activity in a OSSECO-community?	Count the number of events and people that participate in these events	Use list of events attendees and calculate: A=Number of people participating in an event. B=Number of events C=Event regularity	More people are better and more events are better [22].	Data source: content management system [17].	H

3.2.2 Sustainability

Heterogeneity

OSSECOs are global and complex interconnected and distributed community-oriented model of software development and services. This characteristic of OSSECO creates a wide range of diversity and heterogeneity. Because of this, governance, goals, community structure and mechanisms, and business models have continued to diverge. In order to maintain healthy growth of divergent OSSECO-community projects, it is necessary to provide a basic framework to describe this diversity and heterogeneity [36]. Table 3 shows the *Heterogeneity* measures.

Table 3: Heterogeneity measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
H-GMD	Geographical members distribution	Are the members of the OSSECO-community geographically distributed?	Identify the geographical location of members from the mailing lists. Count the number of the different geographical locations (e.g. countries)	Data base query.	More is better More members distributed implies more heterogeneity.	Data source: OSSECO mailing lists	H
H-MAT	Member activity types	Are the OSSECO-community member distributed across different activity types?	identify the activity types from the file paths and filenames [34]. Count the number of members participating in each activity	Calculate the Gini Index [34]	Closer to 0 is better [29] A zero value for these indices implies a uniform distribution. A value of 1 means inequality.	Data source: OSSECO version control repository system.	H
H-ViOP	Variety in OSSECO-community projects	How many kinds of projects has the OSSECO-community?	Search project information in OSSECO-community data sources	Data base query.	More is better A large variety in projects is an indicator that there are many niches, platforms, domains, etc., in which a new player can become active [17].	Data source:OSSECO projects index, content management system and multi-homing	H
H-VoOP	Variety of OSSECO-community partners	How many kinds of partners has the OSSECO-community?	First partners are classified into species by their characteristics (e.g., private, public) Second calculate the proportions of the species in the entire market as a reference point Calculate for each partner the proportions of different species that is related to.	Calculate the covariance of partner variety with the market	High is better Covariance with market indicates the variety of different partners a partner has.	Experts: OSSECO-partners surveys	A
H-OMD	Organizations members' distributions	How are the affiliations of OSSECO-community members to organizations.	Count the number of organizations in which the OSSECO-community members are affiliated.	N/A	More is better	Experts:OSSECO-partners surveys.	A

Regeneration ability

Regeneration ability is the degree to which the size evolution of a OSSECO community happens at an adequate rate to maintain a sustainable OSSECO size that allows them to survive the loss of some of their human resources [7]. Table 4 shows the *Regeneration ability* measures

Table 4: Regeneration ability measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
RA-CSR	Contributor survival rate	What is the number of surviving contributors in the OSSECO community?	Calculate the OSSECO community contributors that were at the beginning and survived in a period time.	X= number of active contributors that survive Y = number of active contributors at the beginning RA-CSR= X/Y e.g. CSR= 70% implies that 7 contributors survive for each 10 contributors per year.	Higher is better [27]	Data source: OSSECO mailing lists, version control repository system and bug tracking system.	H
RA-CNMR	Community new members rate	Is the number of OSSECO-community members evolving?	Count the number of members that have done their affiliation to the community on a time period.	X = number of active members Y= number of new members in a period of time CNMR= Y/X	Higher is better. More new members more survival likelihood [17]	Data source: OSSECO mailing lists.	H
RA-CNCR	Community new contributors rate	Is the number of OSSECO-community contributors evolving?	Count the number of contributors that had done their first contribution to the OSSECO-community on a time period.	X = number of active contributors Y= number of new contributors in a period of time CNCR= Y/X	Higher is better More new contributors more survival likelihood [17].	Data source: OSSECO mailing lists, version control repository system and bug tracking system.	H

Effort balance

An ecosystem is the result of a delicate and dynamic balance between its interacting components [28]. OSSECO effort balance can be expressed as a function of several variables such as lines of code, number of commits, and number of OSSECO-community members. Table 5 shows the *Regeneration ability* measures.

Table 5: Effort balance measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
EB-CCTR	Contributors commit time rate	How long between commits of all contributors?	Calculate the time between commits Calculate variance of time commits for a contributor Calculate variance of variance of all commits contributors time.	CV=Var(CT) CV= variance of a contributor commit times CCTR=Var(CV)	Lower is better [30].	Data source: OSSECO version control repository system.	A
EB-CPI	Community project involvement	How are the commits contributions distributed in the OSSECO-community projects?	Count the number of each activity in each time interval per OSS-community project.	Calculate per OSSECO-community project: A=Number of commits C= Number of lines changed D=Number of files changed.	Similar percentage of contributions is better	Data source: OSSECO version control repository system.	H
EB-ECoC	Statistical characteristics of commits	How is the variation of commits across OSSECO-community history?	Calculate statistical general values of commits from history data from data sources	Min(D)= minimum number of commits Q1(D)= Lower quartile of commits Median(D)= Median of the commits Q3(D)=Upper quartile of commits Mean(d)= Mean of commits Max(D)= Maximum number of commits	High values are better [12]	Data source: OSSECO version control repository system.	A
EB-CAR	Community activities rate	Are the activities distributions balanced in the OSSECO-community projects?	Compute the Gini Index for all or subset of: commits, mails sent, files changed and bug report reading the data in several time intervals in the OSSECO-community projects.	Calculate the Gini Index between X and Y X= is the cumulated proportion of the population variable. Y= is the cumulated proportion of the income variable.	Closer to 0 is better [29] A zero value for these indices implies a uniform distribution. A value of 1 means inequality.	Data source: OSSECO mailing lists, version control repository system, bug tracking system.	A
EB-SoMR	Sub-communities of members rate	How many sub-communities are the developer involved?	Count the number of sub-communities in which all member are involved in the OSS-community	$SoMR = \frac{\sum^m MR(i)}{n}$ m= Number of community members MR=Number of sub-communities of member i n=Number of sub-communities	It depends of the context	Data source: OSSECO mailing lists.	H
EB-DRR	Developer release rate	How is the developers participation in the OSSECO-community?	Count the number of releases in which each developer has been active on a project.	DRR=SD(X) SD= Standar deviation X=Number of developers releases.	Lower is better	Data source: OSSECO version control repository system.	H

Expertise balance

Developing complex software projects in a OSSECO requires skill and expertise in a share-market domain (e.g., Eclipse OSSECO requires knowledge and expertise in plugins, R OSSECO requires skills in statistics). Expertise is one of the most overarching attributes of OSSECOs [20]. OSSECO adopters and contributors typically share the same level of technical expertise (i.e., mostly developer-to-developer communication [4]). The networks of members in an OSSECO provide expertise on different domains and assist in the creation of solutions or products in the ecosystem. Table 6 shows the *Expertise balance* measures.

Table 6: Expertise balance measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
E-CE	Contributors expertise	How is the expertise of the OSSECO-community contributors?	Count the number of files that contributors have changed and classify this by their file extension.	Classify the expertise of all contributors according his kind of contributions.	High balanced is better A zero value for these indices implies a uniform distribution. A value of 1 means inequality.	Data source: OSSECO version control repository system.	A
E-LoCR	Longevity of contributor rate	How many time is a developer in the OSSECO-community?	Obtain dates of first and final author commits Calculate time between dates	$LoCR = \frac{\sum^m Time(C_i)}{m}$ Time(Ci)= Time of contributor i m=Number of contributors.	High is better [25]	Data source: OSSECO version control repository system.	H
E-CER	Contributor experience rate	How is the experience of the OSSECO-community contributors?	Count the total number of releases in which the contributors were active. Contributor project experience= Number of releases since the contributors first activity on the project.	$CER = \frac{\sum^m NR(C_i)}{m}$ NR(Ci)=Number of releases of contributor i m=number of contributors.	High is better [30]	Data source: OSSECO version control repository system.	H
E-NoPpC	Number of projects per contributor	Does each OSSECO-ecosystem contributor have a OSSECO-community project in which it contribute?	Count the number of projects where contributor	Use Gini Index	Close to 0 is better. A zero value for these indices implies a uniform distribution. A value of 1 means inequality [5].	OSSECO version control repository system.	A

Visibility

Visibility tells us something about the popularity of the OSSECO in the shared market. Healthy ecosystems have many partners that are central players and hence possess a high visibility in the market. Those partners have a high impact and therefore a positive influence towards adopters and towards other partners [5]. OSSECO *Visibility* can be measured as a aggregation of several measures such as the amount of requests or feedback received to the OSSECO web site, the number of hits the OSSECO gets in the media and blogs and what is the amount of activity on the project's

visibility in the social media, e.g. Twitter and Facebook [22], the number of OSSECO events, patents and so on. Finally, greater visibility is useful in convincing potential adopters to collaborate with the OSSECO. Table 7 shows the *Visibility* measures.

Table 7: Visibility measures

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
V-NMMNFR	Number of members making new features requests	How many members are making new features requests?	Count the number of OSSECO-community members that are making new features or inquiries	Data base query	More is better [22]	Data source: version control repository system. bug tracking system.	H
V-NoJA	Number of Job advertisements	Are there job opportunities for the OSSECO-community members?	Search job advertisements for OSSeco-community members.	Crawler query.	More is better [22]	Data source: specialized social networks and web sites.	H
V-NoD	Number of downloads	Are the OSSECO-ecosystem projects popular?	Count the number of downloads of the OSSECO-community projects.	Crawler and data base queries.	More is better [17].	Data source: OSSECO download web pages and version control repository system.	H
V-NoOMS	Number of OSSECO-community mailing list subscribers.	What is the contributors OSSECO-community size?	Count the number of contributors subscribed to the OSSECO-community mailing lists.	Data base query.	More is better [8, 22].	Data source: OSSECO mailing lists.	H
V-NoPU	Number of passive users	it is equal to S-NoPU					
V-NoSPRtO	Number of scientific publications referencing the OSSECO-community	Are the OSSECO-community data sources used by researchers?	Search for scientific publications about the OSSECO-community in scientific libraries and databases.	Search string	More is better [22]	Data source: digital libraries and scientific databases.	H
V-WaSMH	Web and Social media hits.	Have the OSSECO-community projects visibility on the web	Count the number of hits of the project in: blogs and social media.	Web analytics tool. e.g, Google analytics	More is better [22, 21]	Data sources: blogs and social media web sites.	H
V-NoP	Number of patents	How many patents has the community?	Count the number of patents of the OSSECO-community.	Surveys	More is better [17].	Experts: Community members.	A
V-NoE	Number of events	How is the social activity in the OSSECO community?	Count the number of events and people that participate in these.	Use list of events attendees and calculate: A=Number of people participating in an event. B=Number of events. C=Event regularity.	More people are better. More events are better [22, 8].	Data source: OSSECO: content management system.	H

Cod.	Name	Purpose	Method	Procedure	Interpretation	source	
V-CRaR	Contributor ratings and reputation.	How is the OSSECO-ecosystem contributors reputation?	Obtain contributors data from OSSECO-community data sources and surveys.	$ET = \frac{\sum^n TFR(r_i)}{n}$ <p>TFR=Time interval for first response to a request i n= Number of OSSECO-community requests. Can be established by looking at the contributor standing in the community, their numbers of commits, their individual bug x times.</p>	High is better [17]. High contributors ranking implies more Trustworthiness.	Data Experts: OSSECO contributors Data source:OSSECO web pages.	H
V-GMD	Geographical members distribution	It is equal to H-GMD					
VCA	Community acceptance	How is the OSSECO-community acceptance by commercial organizations?	Obtain information from partnerships about OSSECO-ecosystem acceptance.	Surveys Crawler query	High is better. OSSECO-community acceptance is better [17].	Experts: OSSECO partners.	A OSSECO content management system.
V-NWPROW	Number of web pages referencing the OSSECO-community web page	How many page referenced the OSS-community web page?	Use a specialized software for count the number of web pages.	Web analytics tool. e.g., Google analytics.	More is better[22, 17].	Data sources: World Wide Web.	H

Community cohesion

Cohesion is an indicator of connectedness between members in a OSSECO-community. It is a property that keeps communities' structure safe from risks, guaranteeing their wellbeing and health [31]. Cohesion guarantees an efficient exploitation of core resources, a proper flow of information between species and provides the necessary protective factors against the entrance of new competitors [5]. Table 8 shows the *Community cohesion* measures.

Table 8: Community cohesion measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
CC-CBCR	Community betweenness centrality rate	What is the ability of a node to act as a mediator in the community?	Calculate the betweenness centrality for each node in the network, e.g., nodes can be contributors and edges are messages in the mailing list. Calculate the percentage of nodes with betweenness centrality ≥ 0	$CBCR = \frac{\sum^{NoN} (NB_i > 0)}{NoN}$ BNi = Betweenness centrality node i NoN= Number of nodes	Closer to 1 is better	Data source: OSSECO mailing lists and version control repository system.	A
CC-CoCD	Cluster of collaborating developers	How to identify clusters of developers in an OSS-community?	Define a social network: The nodes are developers and the edges between them represent projects on which the collaborated. Developers which collaborate are positioned closer together.	There are a variety of methods to automatically identify clusters based on the network structure. Count the number of cluster.	A cluster per project is better.	Data source: OSSECO mailing lists and version control repository system.	H
CC-OLOS	Outbound links to other OSSECO sub-communities	How well the OSSECO sub-communities are connected between them?	Identify resources dependencies and construct a network dependencies graph.	X=A+B A= Number of code dependencies B= Number of contributor dependencies.	High is better. Outbound links are a measure of robustness [17].	Data source: OSSECO bersion control repository system.	H
CC-OoKA	Outdegree of keystone actors.	There are keystone actors in the OSS-community?	Define a social network: The nodes are members of OSSECO-community and the edges between them represent any activities on which they collaborated.	OoKA= $\sum^m O(i) \geq 2\sigma + mu$ O(i)= Outdegree of a node i is the number of edges with i as their initial vertex. m= Number of community members. mo= Mean out.	Network with keystone actors are better connected [21] $OoKA \geq 1$ is better	Data source: OSSECO mailing lists, version control repository system, bug tracking system.	A

3.2.3 Network health

Ecosystem cohesion

This subcharacteristics is related to the OSSECO community cohesion, however, the measures are more related to a holistic point of view of the OSSECO. Table 9 shows the *Ecosystem cohesion* measures.

Table 9: Ecosystem cohesion measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
EC- NoNtDO	Number of nodes to disconnect the OSSECO-ecosystem	How is the OSSECO-ecosystem connected?	Define a OSS-ecosystem social network. Calculate the minimum number of nodes that would need to be removed from the network before it becomes disconnected.	Data base query and surveys	More is better.	Data source: OSSECO version control repository system, mailing lists, content management system. Experts: OSSECO members.	H
EC- OoKA	Outdegree of keystone actors	How many keystone actors have he OSSECO?	Define a OSSECO-ecosystem social network. The outdegree of a node v is the number of edges with v as their initial vertex.	Data base query.	High is better. High outdegree implies that the actor plays a large role in the OSSECO.	Data source: OSSECO mailing lists, version control repository system and bug tracking system. Experts: OSSECO members.	H
EC- OCC	OSSCO clustering coefficient	How close are the OSSECO nodes to becoming a complete graph with its neighbors.	Define a social network: The nodes are the OSSECO members/artifacts and edges definitions depend of the type of the ecosystem analysis. (mails, code, project dependencies, resources).	$CC_i = \frac{L_i}{N_i(N_i - 1)}$ <p>where Li is the number of links between the neighboring nodes Ni of node i N is the number of nodes in the network.</p> $OCC = \bar{c} = \frac{1}{n} \sum_1^n CC_i$	Close to 1 is better [27].	Data source: OSSECO mailing lists, version control repository system and bug tracking system. Experts: OSSECO members.	A
EC- NoPC	Number of partners connections	How many connections have the partners in the OSSECO network?	Define a network: partners and projects are the nodes and any communication is a edge. Count the number of connections between central and non-central species or partners.	Data base query and Surveys.	More is better. More number of connections implies more Interrelatedness.	Data source: version control repository system. Experts:OSSECO partners.	H

Information consistency

The communication in a OSSECO has a common vocabulary that presents the summary of the terms used in the OSECO. A common vocabulary is a tool for the members who wants to obtain a general overview of the domain language of a OSSECO. Table 10 shows the *Information consistency* measures.

Table 10: Information consistency measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
IC-OSiVM	OSSECO synonyms in vocabulary map	How to obtain a general overview of the domain language of the OSSECO?	Construct a vocabulary map with the terms in the OSSECO data sources. Identify synonyms	Data base query and Text mining.	A common language is better. Less synonyms is better	Data sources: OSSECO version control repository system, mailing lists and content management system.	A
IC-OSAS	OSSECO sentimental analysis	How is the message vocabulary content in the OSSECO?	Pre-process the email messages. Configure the sentimental words. Score the words. Classify the words.	Data base query	A positive vocabulary is better.	Data sources: OSSECO mailing lists.	A

Synergetic evolution

It is the ability of the subsystems that constitute the whole ecosystem to form a dynamic and stable space-time structure [14, 23]. Synergetic evolution measures the collaboration between the key members in an OSSECO. Table 11 shows the *Synergetic evolution* measures.

Table 11: Synergetic evolution measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
SE-OPD	OSSECO partners distribution	Is the partner distribution over the ecosystem species equality?	Count the number of partners in each OSSECO project	Calculate Gini index	Close to 0 is better A zero value for these indices implies a uniform distribution. A value of 1 means inequality [5].	Experts: OSSECO partners.	A
SE-OP	OSSECO popularity	How is the OSSECO popularity in external companies?	Calculate the information entropy	$E(CT) = - \sum_{i=1}^{i=n} P_i \log_2 P_i$ <p>C=Commercial companies. P=percentage contribution [37].</p>	High is better [37]. If entropy is low the OSSECO is supported by a small number of companies.	Experts: OSSECO partners. OSSECO sponsors.	H
SE-OPCPaE	OSSECO projects community partnership and embeddedness	How is the OSSECO-community projects embeddedness?	Obtain information about partnership model [17]	Crawler query and surveys.	High is better [17]	Data source: OSSECO Content management system. Experts: OSSECO members	H
SE-OR	OSSECO reciprocity	Is there OSSECO reciprocity?	Define a social network: The nodes are the OSSECO members/artifacts and edges definitions depend of the type of the ecosystem analysis(e.g., mails, code, project dependencies, resources).	Reciprocity is the correlation coefficient between the entries of the adjacency matrix of a directed graph.	P>=0 is better. This measures the amount of direct reciprocity (P>0) or antireciprocity (P<0) in networks, with mutual links occurring more and less often than in random networks. The neutral or reciprocal case corresponds to p=0.	Data source: version control repository system, mailing lists and content management system. Experts:OSSECO members.	H

Interrelatedness ability

Interrelatedness is the ability of nodes in an OSSECO to establish connections between them based on the ways developers collaboratively contribute to the OSSECO projects [9]. Table 12 shows the *Interrelatedness ability* measures.

Table 12: Interrelatedness ability measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
IA-OPCE	OSSECO partners connectedness evolution	How is the partners connectedness evolution in the OSSECO?	Define a OSSECO social network. Number of relations as a proportion of the theoretically maximum number of relations in all network.	Data base and crawler queries.	Growing is better. High connectedness is a property that keeps OSSECO structure safe from risks, guaranteeing their well-being and health.	Data source: OSSECO version control repository system, mailing lists, content management system. Experts: OSSECO members.	H
IA-OPOOMCE	OSSECO partners with other OSSECO members connectedness evolution.	How is the partners connectedness with other OSSECO members evolution?	Define a OSSECO social network. Number of relations as a proportion of the theoretically maximum number of relations in all network.	Data base and crawler queries.	Growing is better. High connectedness is a property that keeps OSSECO structure safe from risks, guaranteeing their well-being and health.	Data source: OSSECO version control repository system, mailing lists and content management system. Experts: OSSECO members.	H
IA-OCE	OSSECO centrality evolution.	What OSSECO members tend to be more connected between them?	Define a OSSECO social network. It's possible to calculate several centrality measures: C1= Partner centrality. C2= Project code centrality. C3= Ecosystem code centrality. C4= Files centrality. C5= Centrality of a developer's contributions.	Process are defined in [3]	The centrality is used within network analysis as a measure to indicate the importance of a node in the network.	Data source: OSSECO version control repository system, mailing lists and content management system. Experts: OSSECO members.	H

3.3 Resources health

Niche creation

It is the ability of the OSSECO to increase meaningful members diversity over time [27]. According to [17] Niche creation describe how much opportunity there is in the OSSECO to start as a new niche player. Furthermore, it is one of the measures defined by [15] for evaluating ecosystem health. Niche creation is also, one of the OSEHO platform pillars (Open Source Ecosystem Health Operationalization) defined by [17]. Table 13 shows the *Niche creation* measures.

Table 13: Niche creation measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
NC- NoCToOPA	Number of context types of OSSECO projects applications	Have the OSSECO projects different types of context applications?	Identify the project OSSECO dependencies. Crawl the OSSECO content management system. Identify the project contexts.	Data base and crawler queries.	More is better. A wide variety of OSSECO project applications contexts, will be more supporting for niche creation [17]	Data source: version control repository system and content management system Experts: OSSECO members.	H
NC- NoNLS	Number of natural languages supported	Is the OSSECO multi-language?	Crawl the OSS content management system. Identify different languages in the OSSECO repository.	Data base and crawler queries.	More is better. A wide variety of supported languages, will be more supporting for niche creation [17].	Data source: OSSECO content management system.	A
NC- ViOPT	Variety in OSSECO project technologies.	Does the OSSECO projects support different technologies?	Read information from OSSECO data sources. Identify the OSSECO development technologies.	Data base and crawler queries	wide variety of technologies, will be more supporting for niche creation [17].	Data source: OSSECO version control repository system and content management system. Experts: OSSECO members.	A
NC- NoOPE	Number of OSSECO platform extensions	How many platform extensions have the OSSECO?	Obtain the number of extensions from the version control repository system.	Data base query.	More is better. Each extension is a potential ecosystem niche	Data source: OSSECO content management system.	A
NC- NoNoO	Number of niches of the OSSECO	How many niches have the OSSECO?	Obtain the number of niches.	Data base query and Surveys.	More is better.	Data source: OSSECO version control system. Experts: OSSECO members.	H

OSSECO Knowledge

The open and shared development practices in OSSECOs allow to contributors adding knowledge such as aggregated information, blog posts, and manuals into a common knowledge base and code repositories, indicating also that the OSSECO is healthy [17]. Table 14 shows the *OSSECO Knowledge* measures.

Table 14: OSSECO Knowledge measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
OK- NoAT	Number of activity types	How many types of activities has the OSSECO?	Obtain the type of activity of the OSSECO members.	Data base query and surveys.	More is better [34].	Data source: OSSECO version control repository system. Experts: OSSECO members.	H
OK- NoOA	Number of OSSECO artifacts	Are the contributors adding knowledge to the OSSECO?	Crawl (Counting the knowledge artifacts). Some artifacts can be: A= Blog posts. B= Manuals. C= Translations. D= Marketing materials. E= Scientific papers.	Crawler query.	More is better [17].	Data source: OSSECO content management system, OSSECO Wikis and digital libraries.	H

Vitality

Vitality is the viability and the ability of an OSSECO to expand (i.e., robustness, ability to increase size and strength) of the ecosystem [QuESo Li et al., 2013]. Vitality related metrics are based on the number of distinct OSSECO members, resources and activities in time intervals. Table 15 shows the *Vitality* measures.

Table 15: Visibility measures

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
V-LoP	Liquidity of partners	Can the partner to meet your short-term obligations?	Obtain the financial data from the partner. Calculate de Liquidity for each partner in the OSSECO. Count the number of partners with liquidity ≥ 1 .	LoP=short-term assets / short term liabilities	Less is better. $X < 1$ is dangerous for the partner. $1 \leq X \leq 2$ is normal. $X > 2$ is good [5].	Data source: OSSECO public partners data. Experts: OSSECO members.	H
V-MSoOP	Market share of OSSECO projects	How is the OSSECO projects market shared?	We need to do end-user surveys in order to collect the knowledge and information that is already available, such as market reports, open source evaluations, and other platform popularity data. Finally, on an aggregate level we can analyze, using source code and manifest analysis, how frequently a project is required and used by other projects.	Data base query and surveys.	More is better [17].	Data source: OSSECO content management system, mailing lists and code repositories. Furthermore, if it is possible, to identify the OSSECO-code inclusion in other projects and software ecosystem [17]. Experts: OSSECO final-users.	H

Cod.	Name	Purpose	Method	Procedure	Interpretation	source	
V-SoP	Solvency of partners	Can the OSSECO partners pay their debts?	Obtain the financial data from the partner. Calculate de solvency for each partner in the OSSECO. Count the number of partners with solvency <1.	X=partner's equity /partner's liabilities.	Low is better. $0 \leq X < 1$ is normal $0 \leq 1/3$ may be financial problems $X < 0$ negative equity. $X > 1$ conservatively financed [5].	Data source: OSSECO partners public data. Experts: OSSECO partners.	H
V-BoAP	Buildup of assets of partners	How is the OSSECO partners productivity?	Obtain financial data from the partners. Calculate the total factor productivity over time.	Surveys	High is better [5]	Data source: OSSECO partners public data. Experts: OSSECO partners.	H
V-LO	Limited obsolescence	Are the OSSECO infrastructure obsolete?	Obtain information about OSSECO technologies.	Crawler query.	No obsolete is better [27].	Data source: OSSECO content management system. Experts: OSSECO members.	A
V-CoUEaUC	Continuity of use experience and use cases	How to the OSSECO evolve in response to new technologies?	Obtain list of projects releases technologies information. Compare releases evolve with OSSECO-community platform evolve and programing languages and operating system evolving.	Crawler query. Surveys.	Evolve more rather than changing abruptly is better.	OSSECO: Content management system. General context of the technologies.	A
V-OCA	OSSECO community acceptance	How is the OSSECO community acceptance by commercial organizations?	Obtain information from partnerships about OSSECO acceptance.	Surveys	High OSSECO acceptance is better [17]	Data source: OSSECO Content management system Experts: OSSECO Partners.	A
V-NoPU	Number of passive users	it is equal to S-NoPU			More is better. Passive users are essential for a sustainable OSS-ecosystem [22]		H
V-NoNC	Number of new communities	Are the OSSECO creating new communities continuously	Count the number of new communities in a period of time.	Data base query.	More is better [17].	Data source: OSSECO mailing lists and version control repository system.	H
V-OPaE	OSSECO partnership and embeddedness	How is the OSSECO embeddedness?	Obtain information about partnership model [17].	Surveys.	High embedded is better [17]	Data source: Version control repository system.	A

Trustworthiness

OSSECO Trustworthiness is the ability to establish a trusted partnership of shared responsibility in building an extended period of time [32]. Table 16 shows the *Trustworthiness* measures.

Table 16: Trustworthiness measures.

Cod.	Name	Purpose	Method	Procedure	Interpretation	Source	Type
T-ZSoP	ZETA score of partners	How is bankruptcy score of the OSSECO partners?	Obtain the financial data from the partner. Test the creditworthiness and solvency of a partner [5]. Count the number of OSSECO partners with ZETA score below 1.8. ZETA score = 1.2A+1.4B+3.3C+0.6D+1.0E A = Working Capital/Total Assets B = Retained Earnings/Total C = Earnings Before Interest Tax/Total Assets D = Market Value of Equity/Total Liabilities E = Sales/Total Assets (P4 Altman)	Surveys	High is better. A score below 1.8 means the company is probably headed for bankruptcy [5]	Data source: partners public financial data. Experts OSSECO partners.	H
T-OA	OSSECO Age	How old is the OSS-ecosystem?	Calculate lifetime of the OSSECO	OE= B-A A= Date of first commit B= Date of last commit	Older is better [29].	Data source: OSSECO version control repository system.	A
T-NoPoP	Number of patents of partners	How many patents has the OSSECO partners?	Count the number of patents of the OSS- ecosystem partners.	Surveys	More is better [17]	Data source: OSSECO partners.	A
T-CRaR	Contributor ratings and reputation	How is the OSSECO contributors reputation?	Obtain contributors data from OSSECO datasources and surveys.	$ET = \frac{\sum^n TFR(r_i)}{n}$ TFR= Time interval for first to a request i n= number of OSSECO requests. Can be established by looking at the contributor standing in the community, their numbers of commits, their individual bug x times.	High is better [17]. High contributors ranking implies more Trustworthiness.	Data sources: OSSECO content management system. Experts: OSSECO members.	A

References

- [1] R. Abreu and R. Premraj, “How developer communication frequency relates to bug introducing changes,” in *Proceedings of the IWPSE and Evol Workshops*, (New York, NY, USA), pp. 153–158, ACM, 2009.
- [2] N. Bettenburg, A. Hassan, B. Adams, and D. German, “Management of community contributions,” *Empirical Software Engineering*, pp. 1–38, 2013. P67.

-
- [3] P. Bonacich, “Power and centrality: A family of measures,” *American journal of sociology*, pp. 1170–1182, 1987.
- [4] N. Dai, W. Thronicke, A. R. Lopez, F. C. Latasa, E. Zeeb, C. Fiehe, A. Litvina, J. Krueger, O. Dohndorf, I. Agudo, *et al.*, “OSAMI Commons - An open dynamic services platform for ambient intelligence,” in *Proceedings of the 16th ETFA*, pp. 1–10, IEEE, 2011.
- [5] E. den Hartigh, W. Visscher, M. Tol, and A. J. Salas, *Measuring the health of a business ecosystem*, ch. 11, pp. 221–246. Vol. 1 of [18], 1st ed., 2013.
- [6] D. Dhungana, I. Groher, E. Schludermann, and S. Biffi, “Software ecosystems vs. natural ecosystems: learning from the ingenious mind of nature,” in *Proceedings of the 4th ECISA*, pp. 96–102, ACM, 2010.
- [7] J. Donald Wynn, *Emerging Free and Open Source Software Practices*, ch. Assessing the Health of an Open Source Ecosystem, pp. 238–258. Idea Group Publishing, 2007.
- [8] M. Foulonneau, R. Pawelzik, B. Grégoire, and O. Donak, “Analyzing the open source communities’ lifecycle with communication data,” in *Proceedings of the 5th MEDES*, pp. 340–344, ACM, 2013.
- [9] O. Franco-Bedoya, D. Ameller, D. Costal, and X. Franch, “Queso: A quality model for open source software ecosystems,” in *Proceedings of the 9th International Conference on Software Engineering and Applications. ICSoft-EA*, July 2014.
- [10] J. Gamalielsson, B. Lundell, and B. Lings, “The Nagios community: An extended quantitative analysis,” in *Proceedings of the 6th OSS*, pp. 85–96, Springer, 2010.
- [11] M. Goeminne and T. Mens, “A framework for analysing and visualising open source software ecosystems,” in *Proceedings of IWPSE-EVOL*, pp. 42–47, ACM, 2010.
- [12] M. Goeminne and T. Mens, *Analyzing ecosystems for open source software developer communities*, ch. 12, pp. 247–275. Vol. 1 of [18], 1st ed., 2013.
- [13] V. K. Gurbani, A. Garvert, and J. D. Herbsleb, “Managing a corporate open source software asset,” *Communications of the ACM*, vol. 53, no. 2, pp. 155–159, 2010.
- [14] H. Haken, “Synergetics,” *Naturwissenschaften*, pp. 121–128, 1980.
- [15] M. Iansiti and R. Levien, “Keystones and dominators: framing operating and technology strategy in a business ecosystem,” tech. rep., Harvard Business School, 2004.

-
- [16] ISO/IEC 25010, “Systems and software engineering systems and software quality requirements and evaluation (square) system and software quality models,” 2011.
- [17] S. Jansen, “Measuring the health of open source software ecosystems: Beyond the scope of project health,” *Information and Software Technology*, vol. 56, no. 11, pp. 1508 – 1519, 2014. Special issue on Software Ecosystems P68.
- [18] S. Jansen, S. Brinkkemper, and M. Cusumano, *Software Ecosystems: Analyzing and Managing Business Networks in the Software Industry*. Cheltenham, UK: Edward Elgar Publishing, 1st ed., 2013.
- [19] S. Jansen, S. Brinkkemper, and A. Finkelstein, “Business network management as a survival strategy: A tale of two software ecosystems.,” in *Proceedings of the 1st Workshop on Software Ecosystems. CEUR-WS*, pp. 34–48, 2009.
- [20] C. Jergensen and A. Sarma, “The onion patch: migration in open source ecosystems,” in *Proceedings of the 19th SIGSOFT and 13th ESEC/FSE*, pp. 70–80, ACM, 2011.
- [21] J. Kabbedijk and S. Jansen, “Steering insight: An exploration of the ruby software ecosystem,” in *Proceedings of the 2nd ICSOB*, pp. 44–55, Springer, 2011.
- [22] T. Kilamo, I. Hammouda, T. Mikkonen, and T. Aaltonen, “From proprietary to open source-Growing an open source ecosystem,” *Journal of Systems and Software*, vol. 85, no. 7, pp. 1467–1478, 2012.
- [23] X. Li, X. Jie, Q. Li, and Q. Zhang, “Research on the Evaluation of Business Ecosystem Health,” in *Proceedings of the 6th ICMSEM*, pp. 1009–1020, Springer, 2013.
- [24] S. Lohmann, S. Negru, F. Haag, and T. Ertl, “Visualizing ontologies with VOWL,” *Semantic Web*, pre-print.
- [25] G. Lucassen, K. van Rooij, and S. Jansen, “Ecosystem health of cloud paas providers,” in *Software Business. From Physical Products to Software Services and Solutions* (G. Herzwurm and T. Margaria, eds.), vol. 150 of *Lecture Notes in Business Information Processing*, pp. 183–194, Springer Berlin Heidelberg, 2013.
- [26] B. Lundell and B. Forssten, “Exploring health within OSS ecosystems,” in *Proceedings of the 1st OSCOMM*, pp. 1–5, 2009.
- [27] K. Manikas and K. M. Hansen, “Reviewing the health of software ecosystems—a conceptual framework proposal.,” in *proceedings of the 5th IWSECO-ICSOB*, pp. 33–44, 2013.
- [28] T. Mens, M. Claes, P. Grosjean, and A. Serebrenik, *Studying evolving software ecosystems based on ecological models*, pp. 297–326. Springer Berlin Heidelberg, 2014.

-
- [29] T. Mens and M. Goeminne, “Analysing the Evolution of Social Aspects of Open Source Software Ecosystems,” in *Proceedings of the 3rd IWSECO*, pp. 1–14, 2011.
- [30] S. Neu, M. Lanza, L. Hattori, and M. D’Ambros, “Telling stories about GNOME with Complicity,” in *Proceedings of the 6th VISSOFT*, pp. 1–8, IEEE, 2011.
- [31] R. E. Rolfe, “Social cohesion and community resilience: A multi-disciplinary review of literature for rural health research,” *Halifax: Department of International Development Studies Faculty of Graduate Studies and Research Saint Marys University*, 2006.
- [32] M. Soto and M. Ciolkowski, “The QualOSS open source assessment model measuring the performance of open source communities,” in *Proceedings of the 3rd ESEM*, pp. 498–501, 2009.
- [33] F. van der Linden, B. Lundell, and P. Marttiin, “Commodification of Industrial Software: A Case for Open Source,” *IEEE Software*, vol. 26, no. 4, pp. 77–83, 2009.
- [34] B. Vasilescu, A. Serebrenik, M. Goeminne, and T. Mens, “On the variation and specialisation of workload: a case study of the gnome ecosystem community,” *Empirical Software Engineering*, vol. 19, no. 4, pp. 955–1008, 2014.
- [35] M. Viljainen and M. Kauppinen, *Framing management practices for keystones in platform ecosystem*, ch. 7, pp. 121–137. Vol. 1 of [18], 1st ed., 2013.
- [36] T. Yamakami, “A three-layer view model of OSS: Toward understanding of diversity of OSS,” in *Proceedings of the 13th ICACT*, pp. 1190–1194, IEEE, 2011.
- [37] L. Yu, J. Cawley, and S. Ramaswamy, “Entropy-Based Study of Components in Open-Source Software Ecosystems,” *INFOCOMP Journal of Computer Science*, vol. 11, no. 1, pp. 22–31, 2012.