Evolution of Software Quality Models: Green and Reliability Issues

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Abstract. The group of attributes (characteristics, requirements) related to green software is essential part of software quality model. It consists of the two main attributes as a resources (energy) saving and sustainability. Evolution of software quality models is analyzed in context of green and reliability. In particular, well known software quality models beginning from on the first McCall's model (1977) to models described in standards ISO/IEC9126 (2001) and ISO/IEC25010 (2010) are analyzed according with green and reliability issues. Comparing of the software quality models are carried out using a special metrics of complexity and technique considering the number of levels and attributes and their semantics. Prediction of complexity for the next software quality model (2020) is fulfilled and variants of green software attributes inclusion in model are proposed.

Keywords. software quality model, green software, software reliability, evolution analysis, metrics, ISO/IEC9126, ISO/IEC25010, structure-semantic analysis.

Key Terms. Model, Reliability, Requirement, SoftwareSystem.

1 Introduction

1.1 Motivation and Work Related Analysis

A set of Software Quality Models (SWQM) has been introduced during evolution of software engineering [1]. Software quality is a degree to which a software product satisfies stated and implied needs when used under specified conditions [2]. Software Quality Model (SWQM) is usually defined as a set of characteristics and relationships between them which actually provide the basis for specifying the requirements of quality, evaluating quality and comparing of SWQMs [3-9]. There are a lot of the models suggested during «software engineering era» [10]. Some of SWQM, described in IEEE, ISO, IEC standards, became well-known and can be called basic. New significant SWQM appear just about once in 10 years. The characteristics and subcharacteristics set and structure (graph-based hierarchy and semantic content) of such SWQMs are changed [11-14]. Generally, these sets are extended and the next SWQM becomes more and more complicated. Changing's of SWQMs are caused by evolution of technologies, new challenges in software engineering and so on.

One of the challenges is development of energy-saving (green) information technologies. It has been caused by appearance of a concept «green software» [15]. Gist of «green software» (GSW) in a broad sense is described by the following words: «decrease» (energy or other resources consumption), «don't do much harm and preserve» (energy, resources, environment) and «improve» (make environment more comfortable and safe). More wide aspects and directions of green and safe/reliable computing are discussed in [16,17].

«Green» characteristics for software are resources saving and sustainability, which were not explicitly defined in well known SWQMs described by standards ISO/IEC9126 [18], ISO/IEC25010 [2]. Analysis of [3,4,6-8] allowing to conclude that SWQMs do not include such characteristics in explicit form.

Taking into consideration the prerequisites for emergence of green characteristics in future SWQMs in direct form we analyze the evolution of the characteristics associated with GSW for existing quality models and try to predict their changing. The analysis will allow defining tendencies of green characteristics and suggesting variants of including some in future SWQMs.

1.2 Goal and Approach

A **goal of the paper** is carrying out of analysis of known software quality models and their development in context of GSW and software reliability. We aim to investigating SWQMs using metric-based approach to assess "weights" of different software quality attributes, first of all, green and reliability characteristics, changing of the weights during evolution of the models and to predict their changing in future.

Stages of the research are the following:

1. Determination of occurrence rates for different SWQM attributes (characteristics at the first level of hierarchy and subcharacteristics at the second one) in different quality models;
2. Selection and analysis of SWQM characteristics which are implicitly associated with green software;
3. Analysis of SWQMs in context green software and reliability by use of complexity metrics and calculation of corresponding weights for attributes;
4. Research of relationship/dependency between metric values for green software, reliability and the years of emergence for known basic SWQMs;
5. Calculation of complexity metric for using results of SWQMs relationship/dependency comparison, described in [11];
6. Calculation of complexity metric for green and reliability attributes of new SWQMs using function describing of dependency between metric values and years of SWQMs emergence;
7. Analysis of SWQM in use in context of green software and definition of possible variants of inclusion of green attributes in new models.

2 SWQM Analysis in Context of Green Software and Reliability

2.1 Analyzed Models

Let’s select and analyse SWQM characteristics which can be implicitly associated with green software and reliability. The results of analysis are shown in Table 1 and Table 2 for green characteristics and reliability characteristics correspondingly. Numeration of the characteristics corresponds with their “places” in hierarchy of SWQMs.

Table 1. SWQM characteristics associated with GSW.

№	SWQMs (years)	GSW characteristics
1.	McCall (1977)	4. Efficiency
		4.1 Execution efficiency
		4.2 Storage efficiency
2.	Boehm (1978)	2.2 Efficiency
		2.2.1 Accountability
		2.2.2 Accessibility
3.	Carlo Ghezzi (1991)	–
4.	FURPS (1992)	4 Performance
		4.1 Velocity
		4.2 Efficiency
		4.3 Availability
		4.4 Time of answer
		4.5 Time of recovery
		4.6 Utilization of resources
		1.2 Capacity
5.	IEEE (1993)	1 Efficiency
		1.1 Temporal efficiency
		1.2 Resource efficiency
6.	Dromey (1995)	2.2 Efficiency
7.	ISO 9126-1 (2001)	4 Efficiency
		4.1 Time behavior
		4.2 Resource utilization
8.	QMOOD (2002)	6 Effectiveness
9.	ISO 25010 (2010)	2 Performance efficiency
		2.1 Time behavior
		2.2 Resource utilization
		2.3 Capacity

Table 2. Reliability characteristics of SWQM.

№	SWQMs (years)	Reliability characteristics
1.	McCall (1977)	2. Reliability
		2.1 Accuracy
		2.2 Error tolerance
		2.3 Consistency
2.	Boehm (1978)	2.1 Reliability
		2.2.1 Self contentedness
		2.2.2 Integrity
		2.2.3 Accuracy
3.	CarloGhezzi (1991)	3. Reliability
4.	FURPS (1992)	3. Reliability
		3.1 Frequency and servity of failures
		3.2 Recoverability
		3.3 Time among failures
5.	IEEE (1993)	2. Reliability
		2.1 Non deficiency
		2.1 Error tolerance
		1.3 Availability
6.	Dromey (1995)	1.2 Reliability
7.	ISO 9126-1 (2001)	2. Reliability
		2.1 Maturity
		2.2 Fault tolerance
		2.3 Recoverability
8.	QMOOD (2002)	-
9.	ISO 25010 (2010)	5. Reliability
		5.1 Maturity
		5.2 Availability
		5.3 Fault tolerance
		5.4 Recoverability

To assess “weights” of green characteristics the technique of SWQM structure-semantic analysis (SSA-technique) can be applied [11]. The technique describes quality models as a facet-hierarchy structure (graph). Nodes corresponds quality attributes and links take into account hierarchy dependencies. To briefly characterize the proposed analysis technique, let us introduce some initial terms:

- conceptual model is a model which a model under study is compared with;
- model under study is a model which is compared with a conceptual model;
- characteristic under study is a conceptual model characteristic which is compared with model under study characteristics.

2.2 Metrics

SSA-technique is based on comparing a model under study with the conceptual model, i.e. every SW Quality Model is compared with the conceptual model. So, the analysis is equivalent to semantic comparing characteristics and subcharacteristics of a model under study and the conceptual model with regard to their structures. Selecting a reference model is usually performed by an expert who has relevant experience and qualifications.

At the following stage comparison of models among themselves should be performed. The simplest and most obvious metrics are offered. Hierarchy of these metrics is presented in Fig. 1. The metrics are used to compare models with reference model bottom up, i.e. first at the level of subcharacteristics (subcharacteristics matching metric SMM, cumulative subcharacteristics comparison metric CSCM, characteristics matching metric CMM), then at the level of characteristics (cumulative matching characteristics metric CMCM) and finally at the level of models as a whole (cumulative software quality models comparison metric CSQMCM).

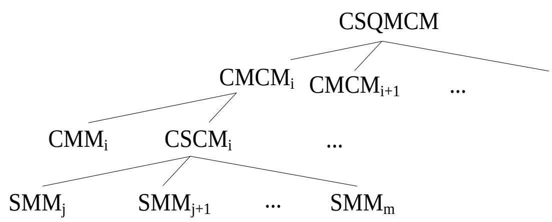

Fig. 1. Metrics hierarchy.

Features of the metrics are the following:

– subcharacteristic matching metric (SMMj). Every subcharacteristic match value is identified as SMMj = 0,5 / number of reference (conceptual) model elements subcharacteristics of the characteristic under study. Weights of characteristics are not considered when calculating metrics;

– cumulative subcharacteristics comparison metric (CSCM) is evaluated as a sum of SMM:

$$CSCM_i = \sum_{j=1}^{k} SMM_j ; \quad (1)$$

– characteristics matching metric (CMM) takes the value of 0.5 in case of matching or 0 if the characteristics are different;

– cumulative matching characteristics metric (CMCM) is calculated as a sum of CMM metric and $\sum_{j=1}^{k} CSCM_j$:

$$CMCM_i = CMM_i + \sum_{j=1}^{k} CSCM_j ; \tag{2}$$

– cumulative software quality models comparison metric (CSQMCM) is calculated according to the formula:

$$CSQMCM_i = \sum_{j=1}^{n} CMCM_j \tag{3}$$

2.3 Results of SWQM Analysis in Context of Green Software and Reliability Characteristics

Let us conduct SW QM analysis and first of all, define the reference (conceptual) model. SW Quality Model ISO/IEC 25010 will be considered as uppermost and etalon regarding to all other models. It is the newest introduced model and takes into account main modern software peculiarities in point of view quality evaluation. This model is described by international standard of top level.

According with results of analysis CMCM is calculated for set of characteristics presented in Table 1. The results of calculation are shown in Table 3 (Chs – characteristics, SChs – subcharacteristics) for GSW characteristics and Table 4 for reliability characteristics.

The histogram of CMCM values for software quality models is presented on Fig. 2. An abscissa axis corresponds to years of SWQM emergence. Initial point (year) is 1970 (as a first year after 1968 which is multiple of a ten years).

CMCM values will be further represented and analysed only for so-called basic SWQMs [18]. Basic models were selected considering their support by standards, the international reputation and application. The models of McCall and Boehm are similar, hence first one was selected. Hence, the models of Boehm, Ghezzi, FURPS, Dromey, QMOOD were excluded (Fig. 3).

The analytical dependency between SWQM appearance year (X axis) and CMCM value (Y axis) for characteristics associated with GSW may be represented by regressive liner function:

$$y = ax+b, \tag{4}$$

where x – variable, a and b - regression coefficients. For 1970 year variable (x) has value 0, for 1980 year x=10, for 1990 year x=20, for 2000 year x=30 and for 2010 year x=40.

Linear subjection was chosen by graphic data analysis (Fig. 3). Satisfiability of applying linear subjection is confirmed by coefficient of determination (R2) which equals 0,94.

Table 3. Results of GSW characteristics comparison and CMCM calculation.

Conceptual model (ISO 25010)		**McCall model**				**Boehm model**				**Ghezzi model**			
Chs	SChs	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM
2		4		0,5	0	-	2.2	0	0,5	-	-	0	0
	2.1	-	-	0	0	-	-	0	0	-	-	0	0
	2.2	-	-	0	0	-	-	0	0	-	-	0	0
	2.3	-	-	0	0	-	-	0	0	-	-	0	0
				CMCM=0,5				CMCM=0,5				CMCM=0	

Conceptual model (ISO 25010)		**FURPS Model**				**IEEE Model**				**Dromey model**			
Chs	SChs	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM
2		-	4.2	0	0,5	1	-	0,5	0	-	2.2	0	0.5
	2.1	-	-	0	0	-	-	0	0	-	-	0	0
	2.2	-	4.6	0	0,17	-	1.2	0	0,17	-	-	0	0
	2.3	-	1.2	0	0,17	-	-	0	0	-	-	0	0
				CMCM =0,84				CMCM =0,67				CMCM =0,5	

Conceptual model (ISO 25010)		**ISO 9126 model**				**QMOOD model**			
Chs	SChs	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM
2		4	-	0,5	0	2	-	0,5	0
	2.1	-	4.1	0	0,17	-	-	0	0
	2.2	-	4.2	0	0,17	-	-		0
	2.3	-	-	0	0	-	-	0	0
				CMCM=0,84				CMCM=0,5	

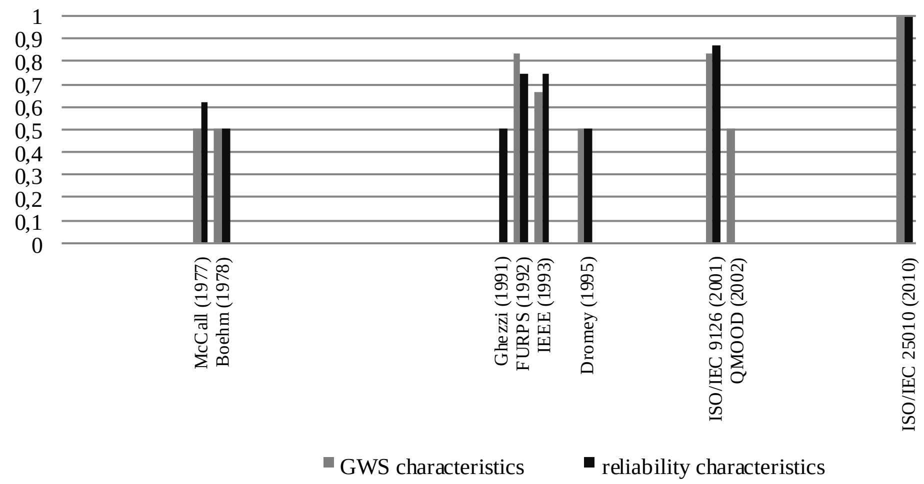

Fig. 2. CMCM values for GSW and reliability characteristics of SWQMs.

Table 4. Results of reliability characteristics comparison and CMCM calculation.

Conceptual model (ISO 25010)		**McCall model**				**Boehm model**				**Ghezzi model**			
Chs	SChs	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM
5		2.	-	0,5	0	-	2.1	0	0,5	3	-	0,5	0
	5.1	-	-	0	0	-	-	0	0	-	-	0	0
	5.2	-	-	0	0	-	-	0	0	-	-	0	0
	5.3	-	2.2	0	0,125	-	-	0	0	-	-	0	0
	5.4	-	-	0	0	-	-	0	0	-	-	0	0
				CMCM=0,625				CMCM=0,5				CMCM=0,5	

Conceptual model (ISO 25010)		**FURPS Model**				**IEEE Model**				**Dromey model**			
Chs	SChs	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM
5			3.	-	0,5	2		0,5	0		1.2,2.3, 3.4,4.4	0	0,5
	5.1	5.1	-	-	0	-	-	0	0	-	-	0	0
	5.2	5.2	-	4.3	0	-	2.3	0	0,125	-	-	0	0
	5.3	5.3	-	-	0	-	2.2	0	0,125	-	-	0	0
	5.4	5.4	-	3.2	0	-	-	0	0	-	-	0	0
				CMCM =0,75				CMCM =0,75				CMCM =0,5	

Conceptual model (ISO 25010)		**ISO 9126 model**				**QMOOD model**			
Chs	SChs	Chs	SChs	CMM	SMM	Chs	SChs	CMM	SMM
5		2	-	0,5	0	-	-	0	0
	5.1	-	2.1	0	0,125	-	-	0	0
	5.2	-	-	0	0	-	-	0	0
	5.3	-	2.2	0	0,125	-	-	0	0
	5.4	-	2.3	0	0,125	-	-	0	0
				CMCM=0,87				CMCM=0	

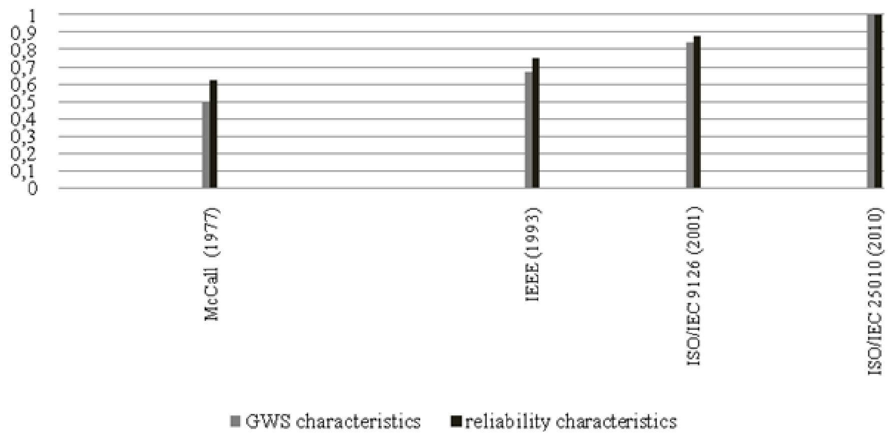

Fig. 3. CMCM values for GSW and reliability characteristics of basic SWQMs.

The values of parameters a and b can be calculated using Least Square Method:

$$a = \frac{n \sum_{i=0}^{n} x_i y_i \quad \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \sum_{i=1}^{n} x^2 \quad (\sum_{i=1}^{n} x_i)^2}, \qquad (5)$$

$$b = \frac{\sum_{i=1}^{n} y_i \quad a \sum_{i=1}^{n} x_i}{n}. \qquad (6)$$

As a result a = 0.0146, b = 0.4108 and function:

$$y = 0.0146x+0.4108. \qquad (7)$$

The obtained function may be called a law of increasing of characteristics associated with GSW for SWQM.

The similar dependency can be obtained for reliability characteristics. In this case a = 0.011, b = 0.5 and function:

$$y = 0.011x+0.5. \qquad (8)$$

Formulas 7 and 8 illustrate a tendency of SWQMs characteristics/ subcharacteristics changes. Analysis of dependencies (Fig.3) allows concluding that weights of green and reliability characteristics became equal in 2010 (the standard ISO/IEC 25010). Hence, since first SWQMs the characteristics/ subcharacteristics related to green attributes have faster dynamics of increasing.

3 Development of SWQM in Context of Green Software

We can assume that the next general SWQM will include GSW characteristics in an explicit form. Let's analyse SWQM evolution tendency in context GSW as a whole. CSQMCM for SWQM may be calculated as shown in formula (3). It may be appeared for future model (2020 year). In compliance with [11] and basing on the analytical relationship between SWQM appearance year (X axis) and CSQMCM value (Y axis) the following formula may be obtained:

$$y=0,153x+1,363. \qquad (9)$$

Besides, considering that each new SWQM approved as a standard is received about once per 10 years, and that the last model was introduced by the standard ISO/IEC 25010 appeared in 2010 the prediction of the CSQMCM value can be done. With this in mind:

$$CSQMCM = 0,153*50 + 1,363= 9,013. \qquad (10)$$

CSQMCM values change is illustrated in Fig. 4 as a histogram for the well known base SWQM as columns of gray and subsequent SWQM 2020 as a column of light gray column.

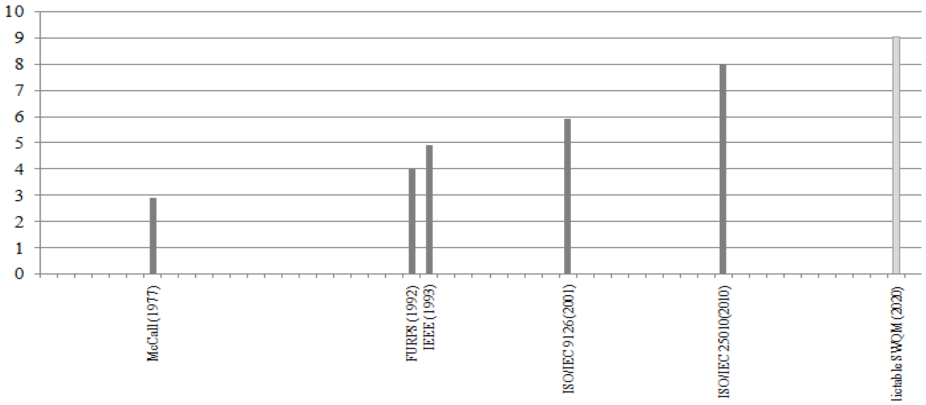

Fig. 4. CSQMCM values for known and predictable SWQMs.

According to the obtained dependence (4) CMCM for green software characteristics is calculated for predictable SWQM 2020 (Fig. 5).

$$y=0,0146*50+0,4108=1,1408. \quad (11)$$

And CMCM for reliability characteristics is calculated for predictable SWQM 2020 (Fig. 5).

$$y = 0,011*50+0,5=1,05. \quad (12)$$

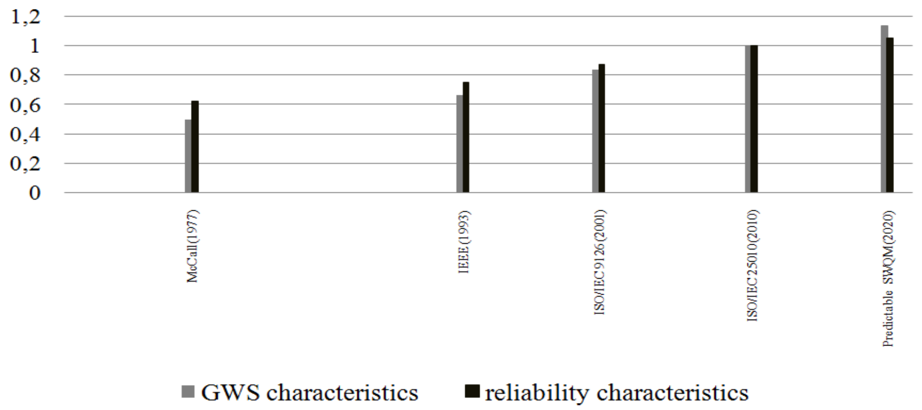

Fig. 5. CMCM values for reliability characteristics and green characteristics for basic SWQMs.

CMCM values of SWQM 2020 for characteristics associated with «green» software exceed the value of the same metric for SWQM ISO/IEC 25010 by 0.1408.

CMCM values of SWQM 2020 for reliability characteristics exceed the value of the same metric for SWQM ISO/IEC 25010 by 0.05.

Analysis of dependencies (Fig.5) allows predicting that green characteristics number will increase faster comparing with other more conservative characteristics.

4 GSW Oriented ON Extending of SWQMs

Taking into account predictable changing of SWQMs let's analyse how content of such models may be added including software quality models in use.

4.1 Variants of GSW Characteristics Inclusion in SWQM

In the following, possible variants are shown of inclusion of GSW characteristics and its components in a SWQM.

1. GSW characteristic can be introduced in SWQM as a separated characteristic with subcharacteristics *resources saving* and *sustainability*. It should be noted that usually *resources saving* excludes *resource utilization* from *performance efficiency* characteristic (Fig. 6).

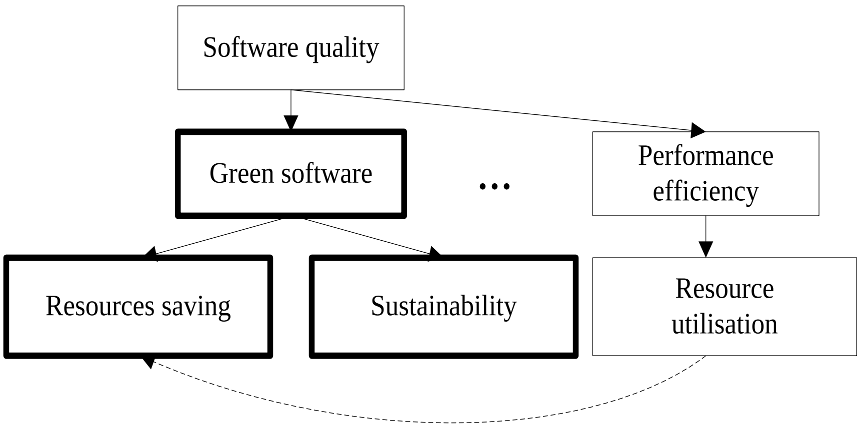

Fig. 6. Green software characteristics in SWQM at the level of characteristics (1).

2. Green software characteristics are not included in SWQM explicitly, but subcharacteristics can go in to SWQM (Fig. 7). *Resources saving* goes in to SWQM as the subcharacteristic in place of *resource utilization*. Subcharacteristic *sustainability* goes in to SWQM as separated characteristic.

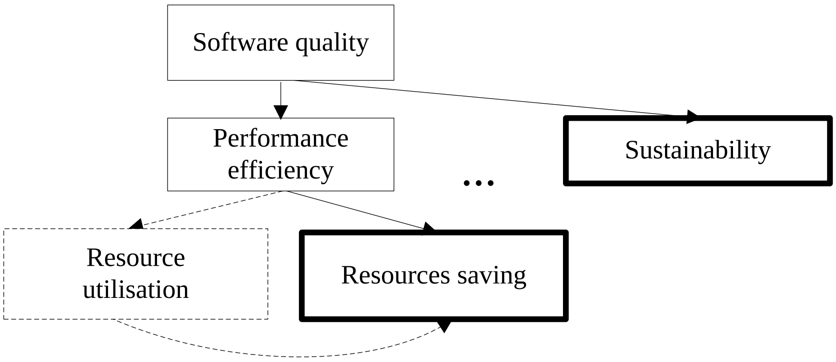

Fig. 7. «Green» software characteristics in SWQM at the level of characteristics and subcharacteristics (2).

3. GSW characteristic cannot be explicitly included in SWQM, but subcharacteristics can be explicitly included (Fig. 8). *Resources saving* is included in SWQM as subcharacteristic in place of *resource utilization. Sustainability* is included in SWQM as subcharacteristic to characteristic *security*.

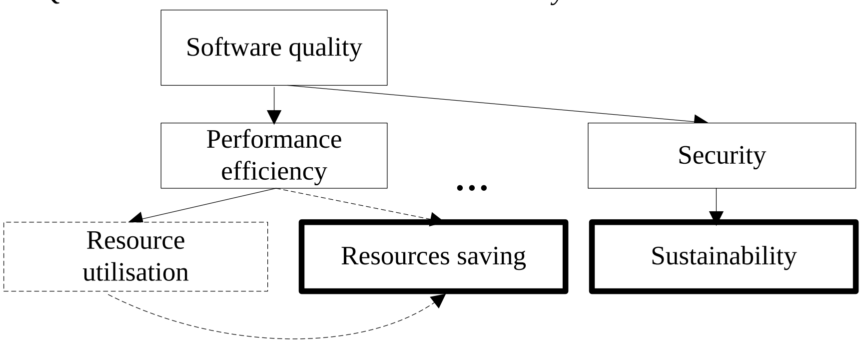

Fig. 8. Green software characteristics in SWQM at the level of subcharacteristics (3).

4.2 SWQM in Use. Analysis in Context of GSW

The standards ISO/IEC9126 and 25010 describe a separate type of models - software quality models in use (SWQM-U). SWQM-U is a capability of the software product to enable specified users to achieve specified goals with effectiveness, productivity, safety and satisfaction in specified contexts of use [18]. The SWQM-Us include characteristics, which can be associated with GSW subcharacteristics, in particular resources saving and sustainability:

– **for SWQM-U, ISO/IEC 9126**: *resources saving – productivity; sustainability – safety. Productivity* is a capability of the software product to enable users to expend appropriate amounts of resources in relation to the effectiveness achieved in a specified context of use. *Safety* is a capability of the software product to achieve acceptable levels of risk of harm to people, business, software, property or the environment in a specified context of use. Risks are usually a result of deficiencies in the functionality (including security), reliability, usability or maintainability;

– **for SWQM-U, ISO/IEC 25010**: *resources saving – efficiency*; *sustainability – freedom from risk, which include 3* subcharacteristics – *economic risk mitigation, health and safety risk mitigation and environmental risk mitigation. Efficiency* is a ratio of expended resources to the accuracy and completeness with which users achieve goals. *Freedom from risk* is a degree to which a product or system mitigates the potential risk to economic status, human life, health, or the environment.

Correlation of SWQM-U characteristics for standards ISO/IEC 9126 and 25010, which are implicitly associated with «green software» and among themselves is shown in Fig. 9.

Thus, GSW related characteristics should be taken into account on development of the next SWQM (SWQM-U) as well.

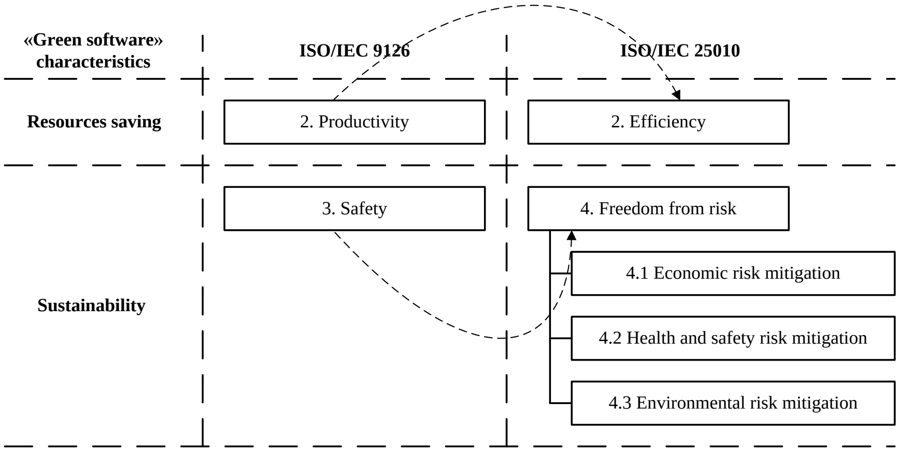

Fig. 9. Correlation of characteristics of SWQM-Us (ISO/IEC 9126 and ISO/IEC 25010) with GSW characteristics.

5 Conclusions

In compliance with SWQM structural and semantic analysis technique we have analyzed SWQM of standards ISO/IEC 9126 and 25010 in context characteristics associated with green software. Using SSA-technique, a relationship between the year of the SWQM appearance and the value of CMCM was obtained and analyzed. Besides, we have calculated the CMCM values for the green software characteristics of the next SWQM, the output of which may be expected in 2020.

It was also obtained the value of metric - CSQMCM for SWQM of 2020, which exceeds the value of this indicator for SWQM ISO/IEC 25010 (Fig. 4). It may be explained by possible inclusion of green software characteristics in SWQM explicitly.

According with results of analysis we can conclude that:

- since first SWQMs the characteristics/ subcharacteristics related to green attributes have faster dynamics of increasing;

- weights of green and reliability characteristics became equal in the standard ISO/IEC 25010;
- it is predicted faster increasing of number green characteristics comparing with other more conservative characteristics.

However, implementation of green characteristics in future quality models should be harmonized with basic attributes such as reliability.

In the future we plan to investigate every SWQM characteristic separately. The data obtained in this case will provide development of a prototype of the new SWQM.

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