# On Sustainability metrics and measures


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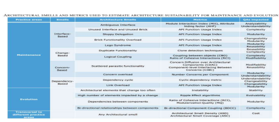

***Informatics Europe Meeting, Malta, October 2024***

# Rafael's research



## I started around 2012 working on sustainability topics…

- First publication in 2013 about sustainable design decisions
- Moving after to sustainability metrics in software architecture (i.e. architecture decay) 2015-today→Systems endurance
- Sustainability in education, skills demanded: 2021-today
- Understand sustainability as a high-level cross-cutting quality attribute affecting the development of systems
- Without metrics and KPIs we cannot estimate how sustainable our systems are
- 11 papers + 1 special issue published since 2013

# Sustainability dimensions



- **Environmental sustainability:** Good set of metrics to estimate Green ICT/IT or sustainable ICT in various domains (e.g. climate, transportation, energy, etc)
- **Technical/Software sustainability:** A significant number of metrics to measure sustainable aspects of software systems (develop sustainable systems or use software to evaluate sustainability aspects). Lack of a global sustainability indicator
- **Social/Individual**: Less explored and hard to evaluate the impact of sustainability initiatives in society and individuals
- **Economic:** Cost factors evaluating sustainability actions

# Software sustainability metrics

- More than 40 code metrics to evaluate different quality aspects of code bases
- Lack of a clear sustainability indicator (e.g. the case of maintainability) and how to combine existing metrics (e.g. complexity, coupling, instability, etc)
- Many software metrics related to estimate technical debt can be used
  - Time/Effort to pay the debt
  - Detection of quality loss
  - TD ratings assess on quality defects

# Software sustainability metrics



- Architecture metrics can help to evaluate sustainability from a different angle

| # | Source | Abbr. | Name |
|---|---|---|---|
| **Similarity of Purpose** | | | |
| M7 | Sarkar2007 | CDM | Concept Domination Metric |
| M7 | Sarkar2007 | CCM | Concept Coherency Metic |
| M7 | Sarkar2007 | APIU | API Function Usage Index |
| M6 | Sant'anna2007 | CDAC | Concern Diffusion over Arch. Components |
| M11 | Sethi2009 | CS | Concern Scope |
| M11 | Sethi2009 | CO | Concern Overlap |
| **Encapsulation** | | | |
| M1 | Briand1996 | RCI | Ratio of Cohesive Interactions |
| M1 | Briand1996 | IC | Import Coupling |
| M1 | Briand1996 | EC | Export Coupling |
| M3 | Mancoridis1998 | MQ | Modularization Quality |
| M5 | Martin2003 | Ca | Afferent Couplings |
| M5 | Martin2003 | Ce | Efferent Couplings |
| M6 | Sant'anna2007 | CLIC | Comp.-level Interlacing Betw. Concerns |
| M6 | Sant'anna2007 | LCC | Lack of Concern-based Cohesion |
| M7 | Sarkar2007 | MII | Module Interaction Index |
| M7 | Sarkar2007 | NC | Non-API Function Closedness Index |
| M7 | Sarkar2007 | IDI | Implicit Dependency Index |
| M8 | Sarkar2008 | BCFI | Base class fragility index |
| M8 | Sarkar2008 | IC | Inheritance-based intermodule coupling |
| M8 | Sarkar2008 | NPII | Not-programming-to-interfaces Index |
| M8 | Sarkar2008 | AC | Association-induced coupling |
| M8 | Sarkar2008 | SAVI | State Access Violation Index |
| M10 | Anan2009 | IEAS | Entropy of an architectural slicing |
| M10 | Anan2009 | ASC | Architecture Slicing Cohesion |
| M11 | Sethi2009 | DV | Decision Volatility |
| **Compilability, Extendibility, Testability** | | | |
| M2 | Lakos1996 | CCD | Cumulative Component Dependency |
| M2 | Lakos1996 | ACD | Average Cumulative Comp. Dependency |
| M2 | Lakos1996 | NCCD | Normalized Cumulative Comp. Dependency |
| M4 | Allen2001 | COUM | Coupling of a module |
| M4 | Allen2001 | ICM | Intramodule coupling of a module |
| M4 | Allen2001 | COHM | Cohesion of a module |
| M5 | Martin2003 | A | Abstractness |
| M5 | Martin2003 | I | Instability |
| M5 | Martin2003 | DMS | Distance from the Main Sequence |
| M7 | Sarkar2007 | MISI | Module Interaction Stability Index |
| M7 | Sarkar2007 | NTDM | Normalized Testability Dependency Metric |
| M8 | Sarkar2008 | PPI | Plugin Polution Index |
| M11 | Sethi2009 | CI | Change impact |
| M11 | Sethi2009 | IL | Independence Level |
| **Acyclic Dependencies** | | | |
| M5 | Martin2003 | PDC | Package Dependency Cycles |
| M7 | Sarkar2007 | Cyclic | Cyclic Dependencies Index |
| M7 | Sarkar2007 | LOI | Layer Organization Index |
| M9 | Sangwan2008 | XS | Excessive Structural Complexity |
| **Size** | | | |
| M7 | Sarkar2007 | MSBI | Module Size Boundness Index |
| M7 | Sarkar2007 | MSUI | Module Size Uniformity Index |

ARCHITECTURAL SMELLS AND METRICS USED TO ESTIMATE ARCHITECTURE SUSTAINABILITY FOR MAINTENANCE AND EVOLUTION

| Practice areas | Smells | Architecture Smells | Metrics | QAs impacted |
|---|---|---|---|---|
| Maintenance | Interface-Based | Ambiguous Interface | Module Interaction Index (MII), Attribute hiding factor (AHF) | Analyzability Understandability |
| | | Unused Interface and Unused Brick | API Function Usage Index | Complexity |
| | | Sloppy Delegation | API Function Usage Index | Modularity |
| | | Brick Functionality Overload | API Function Usage Index | Changeability Modularity |
| | | Lego Syndrome | API Function Usage Index | Modularity Reusability |
| | Change-Based | Duplicate Functionality | Clone detection techniques | Reusability Complexity |
| | | Logical Coupling | Coupling between objects (CBO) Ratio of Cohesive Interactions (RCI) | Complexity Modifiability |
| | Concern-Based | Scattered parasitic functionality | Concern Diffusion over Architectural Components (CDAC) Component-level Interlacing Between Concerns (CIBC) | Modifiability Reusability |
| | | Concern overload | Number Concerns per Component | Modularity Understandability |
| | Dependency-Based | Dependency cycle | Cyclic dependency metric | Understandability Changeability |
| | | Link Overload | API Function Usage Index | Changeability Modularity |
| Evolution | | Architectural elements that change too often | Instability | Stability |
| | | High number of elements impacted by a change | Ripple Effect algorithms | Evolvability |
| | | Dependencies between components | Ratio of Cohesive Interactions (RCI), Modularization Quality (MQ) | Modularity |
| | | Bi-directional relationships between components | Bi-directional Component Coupling (BDCC) | Complexity |
| Transversal to different practice areas | | Any Architectural smell | Architectural Smell Density (ASD) Architectural Smell Coverage (ASC) | Cost |

# Environment sustainability indicators



- There are **plenty of metrics to estimate the green aspects of systems**
- Several domains can benefit of estimating environmental sustainability and green ICT (e.g. waste and resource mgmt., transportation, energy, manufacturing, and many more)
- We **need to standardize these metrics** and its correct use provided by annual sustainability reports
- It is **key to define good KPIs** used by the metrics as indicators to be measure (e.g. context data, resource usage)
- Some rankings use environment indicators to rank most sustainable organizations

# Environment sustainability indicators



- Annual sustainability reports from companies
- We studied 14 international companies using their sustainability reports and web sites as baseline
- Uncover metrics used, ESGs, SDGs, and sustainability dimensions covered

**Table 4.** Sustainability dimensions including ESG areas and sustainability goals addressed

| Company | Sustainability dimensions | ESGs | SDGs |
|---|---|---|---|
| AuraQuantic | Environmental | N/A | 9, 13 but poorly described |
| BABEL | Technical, Economic, Environmental | For an investment to be considered sustainable, it must meet certain ESG criteria which encompass, firstly, the environmental factor to take decisions according to how the activities of companies affect the environment | 3, 5, 13 (diversity, human rights, health care, environment, responsible investment) |
| CGI | Environment (energy, waste, biodiversity), Social (People and Communities) | ESG Report available at web pages | Directly impacting 3,4,5,10,12,13 and indirectly 8, 9, 11,17. Targets have been given but no clear indicators have been set |
| Digia | Planet (co2 emissions, circular economy, green IT and green coding activities), People (diversity/inclusion, life long learning) - | Environmental policy with clear targets and actions given in sustainability report | Sustainable digital value (9,10), Sustainable digital expertise (4,8), Sustainable digital life (5,8,13) - clear indicators set in sustainability report |
| FUJIFILM | Environmental, Economic | Report available at web pages | Provides a CSR management system focused on the following goals: 3, 8, 13, 15 |
| Google | Environmental, economic | Report available at web pages | Lead the transition to a more sustainable future focused on the following sustainable goals: 6, 7, 8, 13, 15 |

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# Environment sustainability indicators: CGI example



- Reporting sustainability impact and coarse numbers
- Carbon-emission, e-waste, resources usage
- Impact of social dimension
- Develop future-ready skills

**ESG targets, progress, and achievements***

| | Environment | Social | Social | Governance |
|---|---|---|---|---|
| Targets | **GHG emissions reduction**<br>**Net-zero emissions**<br>**100% renewable electricity** in all our data centers<br>Set near-term **science-based emissions reduction targets** in line with SBTi criteria and recommendations within a maximum of 24 months. | **Our people**<br>**DE&I:** Achieve the **same level of gender diversity** representation at the leadership levels as the company population as a whole **by 2025** | **Our communities**<br>**100% of business units** to implement pro bono projects **by 2026**<br>Reach **twice as many** participants for our education and mentoring programs as CGI Partners **by 2023** | **Board diversity**<br>**30%:** maintain target for women Board of Directors<br>**Supply chain**<br>**70%** of most significant suppliers[1] assessed on environmental and social criteria **by 2025** |
| Progress and achievements | 38.0% ↗<br>reduction of $CO_2e$[2] emissions from 2019[3]<br>**46.9% in 2022**<br>99.5%[4] ✔<br>renewable electricity in all our data centers by calendar year end 2023<br>**76.8% in 2022**<br>43.7% ↗<br>of total energy from renewable sources<br>**35.6% in 2022** | 28.6% ↗<br>women in leadership[5]<br>**27.5% in 2022**<br>44.4% ↗<br>of SBU Presidents are women<br>**33.3% in 2022**<br>35.3% ↗<br>women CGI Partners overall<br>**34.2% in 2022** | 47%<br>of our business units implemented pro bono projects[6]<br>~204,500[7] ✔<br>Participants in our education and mentoring programs, representing 2.2 times the number of our CGI Partners<br>**~502,000 in 2022**<br>89,837 ↗<br>hours of participation in pro bono and volunteering activities<br>**45,019 in 2022** | 40%[8] ✔<br>of women on the Board of Directors<br>**31.3% in 2022**<br>15[8]<br>members of the Board of Directors living in 4 countries, multilingual, representing expertise in more than 12 vertical markets / submarkets<br>65% ↗<br>of most significant suppliers assessed on environmental and social criteria<br>**58% in 2022** |

| GREENHOUSE GAS EMISSIONS BY SOURCES | METRIC TONS OF $CO_2e$ | | | | |
|---|---|---|---|---|---|
| Travel[2] | 53,991 | 31,396 | 13,117 | 25,088 | 38,546 |
| Offices | 35,342 | 27,344 | 25,432 | 23,637 | 20,606 |
| Data centers | 8,941 | 7,526 | 5,235 | 3,434 | 1,734[3] |

# Environment sustainability indicators



- Some metrics are quite easy to compute
- No high-level metrics to indicate how sustainable companies and public organizations are that can be compared in a fair way
- KPIs is the base of these metrics but also the ESG/SDG goals each organization want to achieve
- Each country demands different sustainability achievements

| | | | | | |
|---|---|---|---|---|---|
| Net-zero carbon | Achieve net-zero emissions across all of our operations and value chain by 2030 | | | | |
| | Carbon reduction | Reduce 50% of our combined Scope 1, 2 (market-based), and 3 absolute emissions (versus our 2019 baseline) before 2030 | $tCO_2e$ emissions | N/A | 10.2 million[11] |
| | Carbon-free energy | Run on 24/7 carbon-free energy on every grid where we operate by 2030 | % carbon-free energy | 66% | 64%[12] |


| | | | | | |
|---|---|---|---|---|---|
| Circular economy | Maximize the reuse of finite resources across our operations, products, and supply chains | | | | |
| | Data centers | Achieve Zero Waste to Landfill for our global data center operations | % of data centers at Zero Waste to Landfill | 30% | 38% |
| | Offices | Divert all food waste from landfill by 2025 | % food waste diverted | N/A | 85% |
| | Consumer hardware | Use recycled or renewable material in at least 50% of plastic used across our consumer hardware product portfolio by 2025 | % recycled/ renewable material | 36% | 41% |

# Tools



- **Google carbon footprint calculator**
  - Track emissions of cloud projects
  - Location-based emissions
  - Measure and reduce IT carbon emissions
  - Gross carbon emission by project

**Automated Carbon Emission Calculation for Financial Transactions**

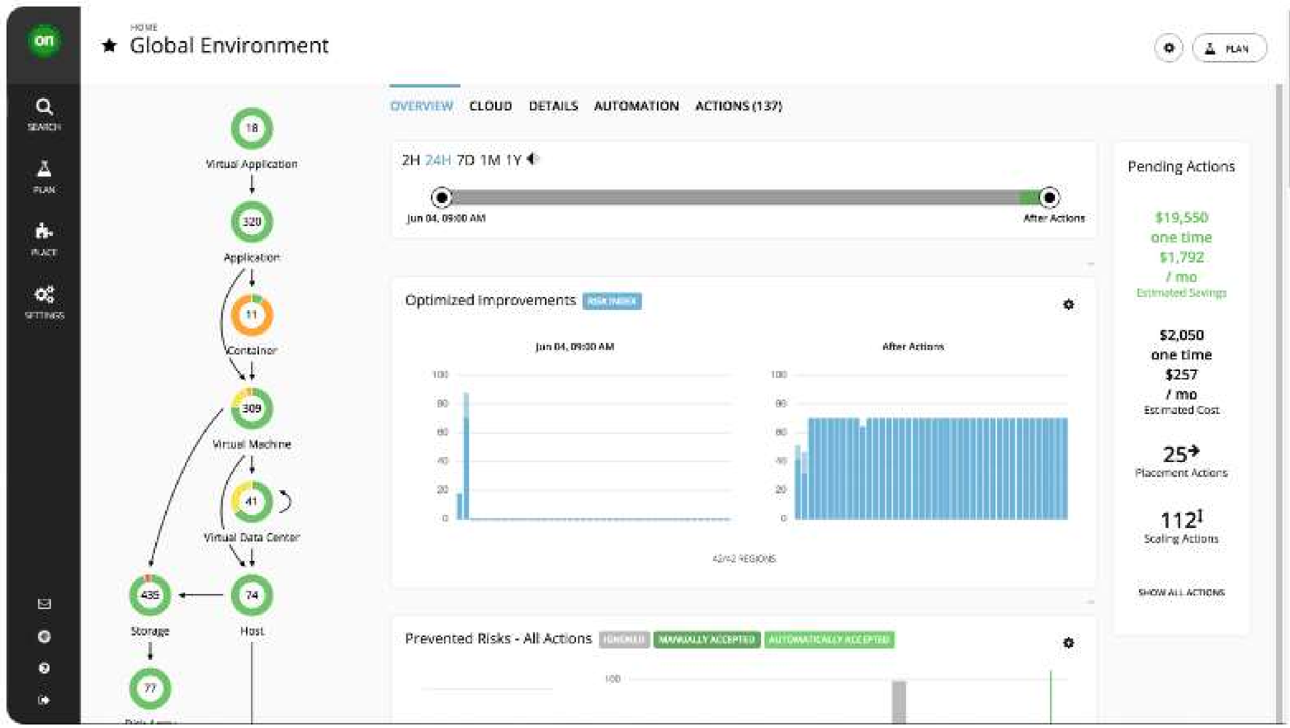
| **Input** provided by the Platform | | | | | **Output** calculated by Climatiq | |
|---|---|---|---|---|---|---|
| **MCC Code** | **Country** | **Spend** | **Currency** | | **Emissions (in kg CO2e)** | **Category** |
| 3100 | Austria | 300 | eur | | 331,26 | Air transport se |
| 3100 | Switzerland | 300 | eur | | 207,63 | Air transport se |
| 5542 | Finland | 1000 | aud | | 104,99 | Retail trade of r |
| 3100 | Belgium | 300 | eur | | 267,87 | Air transport se |
| 3100 | Germany | 500 | eur | | 381,70 | Air transport se |
| 5542 | Bulgaria | 200 | usd | | 115,68 | Retail trade of r |
| 3299 | United States of Ameri | 333 | usd | | 304,79 | Air transport se |
| 5996 | France | 10000 | eur | | 1.881,00 | Furniture/other |
| 5462 | Germany | 5 | eur | | 2,27 | Food products ( |
| 3039 | France | 100 | eur | | 127,05 | Air transport se |

https://cloud.google.com/carbon-footprint?hl=en

# Tools



- **IBM's Turbonomic sustainability IT**
  - Sustainability in data centers
  - Optimize carbon footprint
  - Understand the current usage of IT operations
  - GPU optimization



# Research Agenda



(i) How to combine code and architecture quality indicators to provide a good sustainability estimation

(ii) Too many metrics to estimate environmental sustainability

- (i) Are these metrics applied correctly?
- (ii) Do companies tell the true in their sustainability reports
- (iii) Are metrics standardized?

(iii) How environmental/technical sustainability metrics can be used to evaluate other sustainability dimensions

(iv) Tools available? Which ones?

(v) Use of energy-efficient programming languages (e.g. Rust)

# Thank you for listening

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