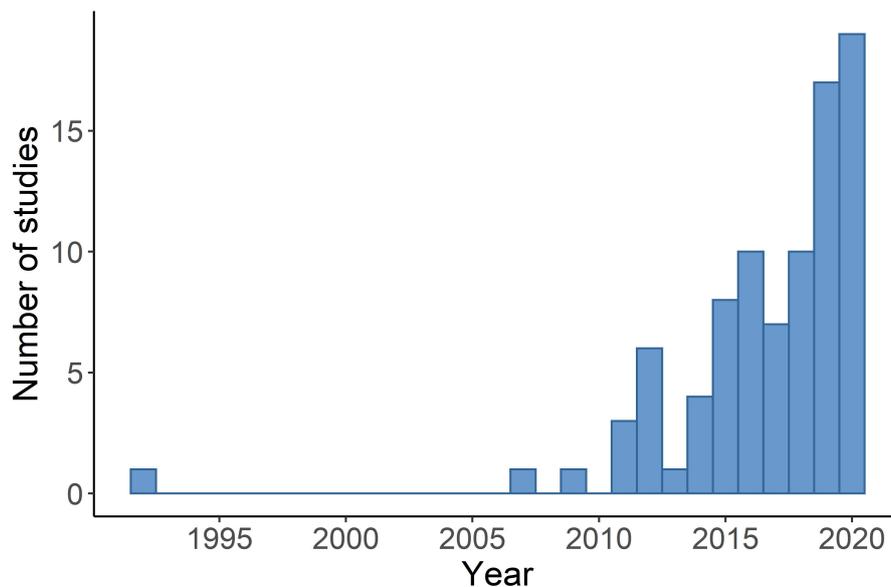
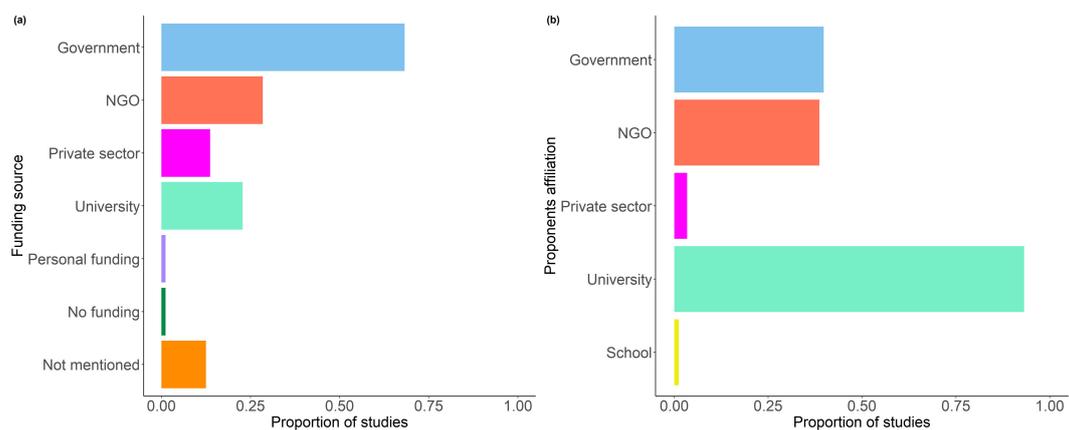


# Supplementary Materials: A Buzz for Sustainability and Conservation: The Growing Potential of Citizen Science Studies on Bees

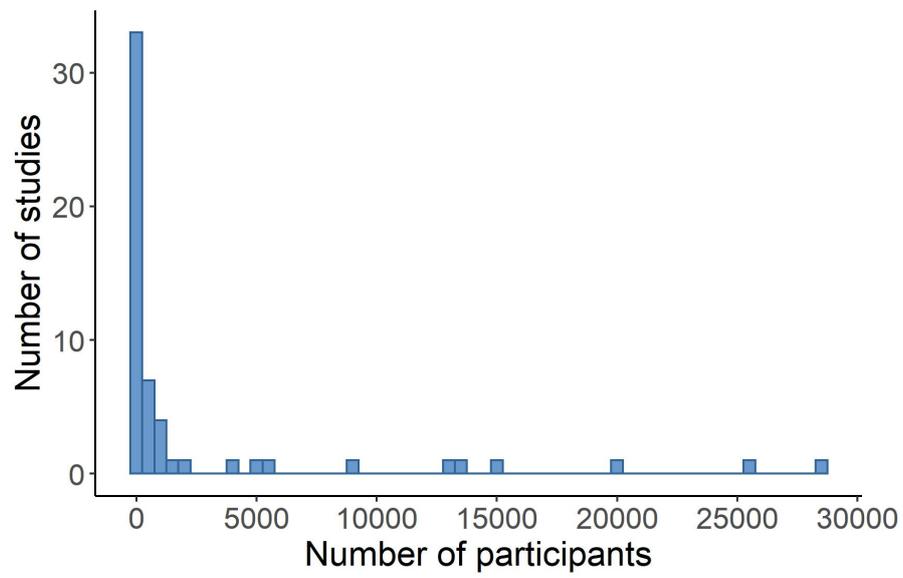
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**Figure S1.** Distribution of citizen science studies on bees published per year, from 1992 to 2020. Dataset includes studies published until September 2020.



**Figure S2.** Proportion of citizen science studies on bees regarding (a) the distinct categories of funding source and (b) proponents affiliations.



**Figure S3.** Distribution of citizen science studies on bees regarding participant number, which varied from 2 to 28,629 participants. Only 53 studies presented the exact number of volunteers engaged in the project.

**Table S1.** Variables assessed in each study retrieved in the systematic review. Details are given for the variable name, information source (A: article or P: project), definition and levels considered for each variable.

| Variable Group   | Variable   | Level [number of studies]     | Level definition   |
|--|--|-------------------------------|--|
| Study Information  | Funding Source (adapted from Cunha et al. 2016) Funding institution cited/acknowledged in the article. (A) | Government [60]               | Government departments and research institutes.  |
|  |  | NGO [25]                      | Nonprofit organizations, associations, societies, charitable trusts, and charitable foundations. |
|  |  | No funding to report [1]      | Authors declared no funding for the research.  |
|  |  | Personal funding [1]          | Authors funding their own study.   |
|  |  | Private sector [12]           | Private organizations, companies, corporations.  |
|  |  | University [20]               | Funded by universities.  |
|  | Proponents (adapted from Cunha et al. 2016) Affiliation of study authors. (A)                              | Not mentioned [11]            | No information provided.   |
|  |  | Government [35]               | Government departments and research institutes.  |
|  |  | NGO [34]                      | Nonprofit organizations, associations, societies, charitable trusts and charitable foundations.  |
|  |  | Private sector [3]            | Private organizations, companies, corporations.  |
| Reach: spatial scale. (A)  | University [82]  | Universities.                 |  |
|  | School [1]   | Authors were school students. |  |
|  | Global [6]   | More than one continent.      |  |
| Country: Country or countries where the project was performed. (A) | Regional [13]  | More than one country.        |  |
|  | Local [69]   | One country.                  |  |
|  | Country name   |                               |  |

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| Project duration: project length and status. (P)   | STF: Short term finished [21]                                  | Less than one year and finished.   |
|  | LTF: Long term finished [17]                                   | More than one year and finished.   |
|  | LTO: Long term ongoing [45]                                    | More than one year and active.   |
|  | Not mentioned [3]  | No information provided.   |
| SDG: Sustainable Development Goal addressed by the study. (A)  | SDG 2: Zero Hunger [6]   | Studies regarding the influence of bees on agricultural production.  |
|  | SDG 4: Quality Education [3]                                   | Studies in which bees were used to promote scientific education.   |
|  | SDG 11: Sustainable cities and communities [7]                 | Studies of the biology of bees in urban landscapes.  |
|  | SDG 15: Life on Land [46]                                      | Studies investigating biological or ecological aspects of bees in general.                                       |
|  | SDG 17: Partnerships [26]                                      | Studies in which establishing a partnership or validating a citizen science project was central in the research. |
| Research area: Research areas explored (when more than one aim was declared, only the main results were considered). (A) | Agricultural practices [2]                                     | Agricultural practices and monitoring.   |
|  | Beekeeping [19]  | Management practices and colony monitoring.  |
|  | Data quality [12]  | Data quality assessment.   |
|  | Distributional Ecology [15](subcategory: Invasive species [6]) | Mapping occurrences and modelling distributions.   |
|  | Landscape Ecology [7]  | Landscape effects and urban biodiversity.  |
|  | Natural History [7]  | Natural history of biological groups.  |
|  | Plant-pollinator interactions [9]                              | Palynology, flower visitors, or sensory ecology.   |
|  | Population ecology [3]   | Population trends, population genetics, or phenology.  |
|  | Project presentation [4]                                       | Project description.   |

|                     |  |   |  |
|---------------------|--|---|--|
|                     |  | Toxicology [2]<br>Volunteer assessment [8].   | Effects of agrochemicals on bees.<br>Assessments on motivation and learning outcomes.  |
|                     | Hypothesis-led. (A)  | Yes [44]<br><br>No [44]   | Authors clearly state the aim is to test hypotheses or there is a study question.<br>Mainly descriptive studies.   |
|                     | Data quality (modified from Wiggins et al. 2011). Strategies employed to improve data quality in the citizen science projects. (A) | Automatic recognition techniques [2]<br><br>Calibrated equipment [6]<br>Digital vouchers [38]<br>Expert review [36]<br>Filtering of unusual reports [3]<br>Personal knowledge [23]<br>Protocols [36]<br>Repeated samples [4]<br>Specimen voucher [14]<br>Training [26]<br><br>Not mentioned [5] | Model for automatic identification<br><br>Calibrated equipment used for measurements or sampling..<br>Photos<br>Data is reviewed by specialists.<br>Identification of outliers.<br>Participant skills and expertise (eg: beekeepers).<br>Structured protocols for data collection.<br>Repeating samples to correct errors.<br>Specimen collected and stored.<br>Specific training mentioned or manuals explaining the methods and research aims.<br>No information provided. |
| Project Information | Project name. (P)  | Project name  | Name of the projects discussed in the article.   |
|                     | Project purpose (modified from Pocock et al. 2017). (P)  | Biological recording [58].<br><br>Biological monitoring [27](subcategory Phenology [2]).<br>Crowd-sourced [1].<br>Technology platforms [2]  | Making a record - when only one record is enough for each participant.<br>Recording over a longer period - more than one record is needed.<br><br>Crowdsourcing data from digital repositories.<br>Technology platforms (provided to facilitate other projects).   |

|                         |  |  |  |
|-------------------------|--|--|--|
|                         | Degree of participation (modified from Bonney et al. 2009). (A)  | Contributory [82]<br><br>Collaborative [2]<br><br>Co-created [3]<br><br>Crowd-sourced data [1]   | Project designed by scientists, public contribute with data collection<br><br>Public contribute with data collection and help refine project design, analyze data, or disseminate findings.<br>Project designed by scientists and Public working together, at least some of the participants are involved in all steps of the scientific process.<br>Crowd-sourced data (data collected non-intentionally by volunteers and gathered from digital repositories). |
| Studied System          | Animal group. Animal groups studied in each article. (A)         | Ant, Bee, Bird, Butterfly, Coleoptera, Diptera, Hymenoptera, Invertebrates, Moth, Wasp.          |  |
|                         | Taxon  | Taxonomic name of the focused group  | If a specific bee was studied among other animals, bee species/genus is specified in parenthesis. "Diverse" was used when no taxonomic group was the focus.  |
|                         | Sociality. The degree to which individuals in social groups. (A) | Both [19]<br><br>Social [58]<br>Solitary [11]  | Both social and solitary insects were studied.<br><br>Only social insects were studied.<br>Only solitary insects were studied  |
| Participant information | Number of participants. (A)                                      | Numeric(min: 2, max: 28,629)   | Number of participants that contributed to the project. Descriptive statistics are based on exact numbers provided in the study (approximations were not considered).  |
|                         | Volunteer Profile.(A)  | Agriculture stakeholders [4]<br>Bee enthusiasts [7]<br>Beekeepers [25]<br>Citizen scientists [4] | Farmers or members of agriculture associations.<br>People interested in bees, members of associations.<br>Professional and hobbyist beekeepers.<br>Recruited from other CS projects.   |

|   |  |                         |   |
|---|--|-------------------------|---|
|   |  | Gardeners [4]           | Home gardeners, organic gardeners, master gardeners (University extension courses). |
|   |  | General Population [43] | Inferred when no other profile was mentioned  |
|   |  | School Students [6]     | School children and teenagers.  |
|   |  | Teachers [2]            | Education professionals.  |
|   |  | University students [4] | Undergraduate students.   |
|   |  | Workers [3]             | Recruited in companies where they work.   |
|   |  | Not mentioned [2]       | No information provided.  |
| Recruitment: methods employed for recruiting volunteers. (A)  |  | Digital media [34]      | Email, social media, website.   |
|   |  | Organizations [38]      | Gardeners groups, NGO participants, associations.                                   |
|   |  | Personal contact [7]    | Personal recruitment by the research team.  |
|   |  | Press media [13]        | Press announcements.  |
| Communication: Methods and tools used to train participants and deliver relevant information about the project. (A) |  | Not mentioned [32]      | No information provided.  |
|   |  | Manuals [20]            | Printed or digital guides provided to the volunteers.                               |
|   |  | Online [43]             | Social media, website, online courses.  |
|   |  | Presencial [19]         | Presencial courses or mentoring.  |
| Volunteer assessment (what?) Learning outcomes and perceptions of volunteers (modified from Keleman-Finam). (A)     |  | Not mentioned [26]      | No information provided.  |
|   |  | Interest [6]            | Liking the procedures of the research that is being done                            |
|   |  | Motivation [5]          | Enjoyment and curiosity towards the subject. Wanting to contribute to science.      |

|   |             |  |   |
|---|-------------|--|---|
|   |             | Knowledge [12]   | Knowledge of the nature of science and ‘understanding of the scientific process and how science is conducted by researchers’. |
|   |             | Behavior [1]   | Close to the motivation, but with a sense of goal. Means what the research wants to accomplish.                               |
|   |             | Attitude [0]   | Sense of awareness about the subject, mainly analysed before and after the study.   |
|   |             | Perception [1]   | How volunteers feel about their participation.  |
|   |             | Not mentioned [65]   | No information provided.  |
| Volunteer assessment (how?).<br>Mechanisms for volunteers<br>assessment. (A)    |             | Drawings [1]   | The volunteers express their participation in draws.  |
|   |             | Interviews [2]   | Usually focused on qualitative data, may be guided by the researcher with other methods simultaneously.                       |
|   |             | Loud thinking [1]  | The volunteer speaks while thinking about the study.  |
|   |             | Questionnaires [11]  | Instrument to collect both quantitative and qualitative data, with innumerable variations of methods.                         |
|   |             | Workshops [3]<br>Not mentioned [67]                            | The volunteers discuss their opinions about their participation.<br>No information provided.                                  |
| Volunteer assessment (when?).<br>In which step volunteers were<br>assessed. (A) |             | Pre survey [1]   | Survey applied before volunteer participation.  |
|   |             | During survey [1]  | Survey applied during volunteer participation.  |
|   |             | Post survey [11]   | Survey applied after volunteer participation.   |
|   |             | Pre/post survey [4]  | Survey applied before and after volunteer participation.  |
|   |             | Not mentioned [67]   | No information provided.  |
| Ethics<br>commitment  | Open Access | Conference proceedings [7] (subcategory: restricted access[2]) | Conference proceedings were considered when no related paper was found.   |
|   |             | Open access journal [23]                                       | Journal’s articles are free to read.  |
|   |             | Open access article in restricted journal [24]                 | The researchers paid to make the article free to read in a restricted journal.  |

|                               |  |  |
|-------------------------------|--|--|
|                               | Restricted access [34]                           | The reader have to pay for the access.   |
| Feedback to participants. (A) | Yes [33]<br>No [1]<br>Not mentioned [54]Yes [70] | Authors mention if any feedback was given to the volunteers.<br>Authors mention no feedback was given to the volunteers.<br>No information provided. |
| Acknowledgements. (A)         | No [18]  | Citizen scientists are acknowledged in the study.<br>Citizen scientists are not acknowledged in the study.   |

**Table S2.** Potential for Sustainable Development Goals reporting and monitoring employing data from citizen science studies with bees. Details are given on which SDGs could be assessed, its respective targets and indicators, and the tier classification from each indicator.

| <b>ECSA Principle</b>  | <b>Compliance criteria</b>   | <b>Variable</b>   |
|--|--|---|
| 1- Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding.                       | Actively involving volunteers in some part of scientific research, with volunteer knowledge and consent.                     | Degree of participation.  |
| 2- Citizen science projects have a genuine science outcome.  | Producing scientific knowledge, whether there is a research question or not.   | Results published in a peer reviewed journal or conference proceedings. |
| 3- Both the professional scientists and citizen scientists benefit from taking part.   | Exhibiting at least one explicit measure to train the volunteers, communicate with the volunteers, or assess their outcomes. | Training or Communication or Volunteer Assessment (any).                |
| 4- Citizen scientists may, if they wish, participate in multiple stages of the scientific process.   | Involving volunteers in more than one step of the scientific process.  | Degree of participation.  |
| 5- Citizen scientists receive feedback from the project.   | Explicitly mentioning that feedback for the participants was provided.   | Feedback to participants.   |
| 6- Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for.     | Exhibiting at least one explicit measure to assure data quality.   | Data quality.   |
| 7- Citizen science project data and meta-data are made publicly available and where possible, results are published in an open access format.      | Publishing results as open access papers, open access papers in restricted journals, or in conference proceedings.           | Open Access.  |
| 8- Citizen scientists are acknowledged in project results and publications.  | Explicitly acknowledging the volunteers who participated in the project.   | Acknowledgements.   |
| 9- Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact. | When assessing data quality, and/or volunteer assessment was the study main aim.   | Research area if it is Data quality or Volunteer Assessment.            |

10- The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities.

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This principle was not evaluated (see main text for explanation).

**Table S3.** Potential for Sustainable Development Goals reporting and monitoring employing data from citizen science studies with bees. Details are given on which SDGs could be assessed, its respective targets and indicators, and the tier classification from each indicator.

| SDG                      | Target   | Indicator  | Tier    |
|--------------------------|--|--|---------|
| SDG 2: Zero Hunger       | 2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality  | 2.4.1 Proportion of agricultural area under productive and sustainable agriculture   | Tier II |
|                          | 2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries  | 2.a.1 The agriculture orientation index for government expenditures  | Tier I  |
|                          |  | 2.a.2 Total official flows (official development assistance plus other official flows) to the agriculture sector   | Tier I  |
| SDG 4: Quality Education | 4.1 By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes   | 4.1.1 Proportion of children and young people (a) in grades 2/3; (b) at the end of primary; and (c) at the end of lower secondary achieving at least a minimum proficiency level in (i) reading and (ii) mathematics, by sex | Tier I  |
|                          | 4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development | 4.7.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment  | Tier II |

|  |      |  |   |         |
|--|------|--|---|---------|
|  |      | 4.c By 2030, substantially increase the supply of qualified teachers, including through international cooperation for teacher training in developing countries, especially least developed countries and small island developing States                | 4.c.1 Proportion of teachers with the minimum required qualifications, by education level   | Tier II |
| SDG 11: Sustainable Cities and Communities | 11.4 | Strengthen efforts to protect and safeguard the world's cultural and natural heritage  | 11.4.1 Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal) | Tier II |
|  | 11.7 | By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities  | 11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities  | Tier II |
| SDG 15: Life on Land                       | 15.1 | By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements | 15.1.1 Forest area as a proportion of total land area   | Tier I  |
|  |      |  | 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type   | Tier I  |
|  | 15.2 | By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally  | 15.2.1 Progress towards sustainable forest management   | Tier I  |
|  | 15.3 | By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world  | 15.3.1 Proportion of land that is degraded over total land area   | Tier I  |

|   |  |         |
|---|--|---------|
| 15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development     | 15.4.1 Coverage by protected areas of important sites for mountain biodiversity  | Tier I  |
|   | 15.4.2 Mountain Green Cover Index  | Tier I  |
| 15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species           | 15.5.1 Red List Index  | Tier I  |
| 15.6 Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed                 | 15.6.1 Number of countries that have adopted legislative, administrative and policy frameworks to ensure fair and equitable sharing of benefits  | Tier I  |
| 15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species | 15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species  | Tier II |
| 15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts  | 15.9.1 (a) Number of countries that have established national targets in accordance with or similar to Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011–2020 in their national biodiversity strategy and action plans and the progress reported towards these targets; and (b) integration of biodiversity into national accounting and reporting systems, defined as implementation of the System of Environmental-Economic Accounting | Tier II |

|                  |   |   |         |
|------------------|---|---|---------|
| SDG Partnerships | 17: 17.9 Enhance international support for implementing effective and targeted capacity building in developing countries to support national plans to implement all the Sustainable Development Goals, including through North-South, South-South and triangular cooperation  | 17.9.1 Dollar value of financial and technical assistance (including through North-South, South-South and triangular cooperation) committed to developing countries                   | Tier I  |
|                  | 17.16 Enhance the Global Partnership for Sustainable Development, complemented by multi stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the Sustainable Development Goals in all countries, in particular developing countries | 17.16.1 Number of countries reporting progress in multi-stakeholder development effectiveness monitoring frameworks that support the achievement of the sustainable development goals | Tier II |
|                  | 17.17 Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships   | 17.17.1 Amount in United States dollars committed to public-private partnerships for infrastructure   | Tier II |

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