Climate Change Adaptation and Mitigation

PIDG Project Classifications and Methodology Review

PIDG Summary and Response

PIDG Climate Change Review

The Private Infrastructure Development Group's (PIDG) purpose is to combat poverty in the poorest and most fragile countries through pioneering infrastructure to help economies grow and change people's lives. .

Measurement of PIDG's development impact is integral to this in two ways:

1. **Accountability**
   PIDG must provide robust evidence to account for and justify the use of public funding. In this, PIDG is accountable to its Owners, host Governments, and to the communities it seeks to serve.

2. **Learning, improving and demonstrating**
   Impact measurement provides PIDG with data that can be used to improve performance and guide our strategy. Sharing knowledge with the wider market also supports PIDG's work to crowd in more investment and promote effective models for infrastructure in low-income countries.

We view independent reviews and evaluations as particularly important tools for accountability and learning. Independent reviews are intended to provide PIDG, our Owners, and other stakeholders with a fresh and objective view on areas of critical importance to PIDG's strategy for delivering positive impact. Independent reviews are advisory, and do not represent PIDG policy, strategy or results reporting.

In 2017, PIDG commissioned the Global Sustainability Institute, Anglia Ruskin University (GSI), to provide an updated, independent classification of PIDG project climate change mitigation and adaptation benefits. GSI also provided PIDG with a review of the classification methodology used by PIDG, in order to ensure that this remains in line with current good practice.

Selected conclusions and recommendations
Although adaptation and mitigation were not strategic objectives for PIDG companies at the time of the review, 22% of projects in PIDG's portfolio at 31 December 2016 were classified as having significant climate change mitigation impact and/or including mitigation as a key objective of the project. These largely relate to renewable energy projects. This compares with a total of 15% in the 2012 portfolio. In addition, 19% of projects were classified as having incremental climate change mitigation co-benefits.

Meanwhile, 7% of projects were classified as leading to significant climate adaptation co-benefits. The remainder were not considered to have adaptation as part of their purpose. However, the reviewers noted that some projects had a positive impact on resilience, for example through food security.

The review recommended:

- An update to the definition of mitigation to include a reference to emission savings over a business as usual scenario and quantification of emissions savings in tier 1 of mitigation.

- A new tier 4 classification for mitigation to include projects that may be the subject of future climate change regulations which could materially impact upon their valuation.
- An additional adaptation classification is introduced to differentiate between project resilience and wider community adaptation, which results in three classifications as follows:
    - Mitigation
    - Community adaptation
    - Project resilience

Since this review was conducted, PIDG has provided new guidance to companies to promote the lowest carbon options for energy generation projects, drafted a new climate change standard that sets expectations for PIDG Companies regarding emissions management and reporting, and commissioned an independent GHG emissions audit of the PIDG portfolio (to be published in 2019).

PIDG has opted to retain the current classification structure, rather than implement new classification types and tiers (i.e. an additional type of project resilience, and additional mitigation tier regarding future regulation). A robust assessment of project resilience to climate change is a basic requirement for PIDG support.

Assessment of future policy and regulatory risk is also embedded within project due diligence, and any higher carbon projects, for example fossil fuel-based energy generation, must provide clear analysis of project utilisation, emissions and comparison with alternatives over the full project lifecycle. Further guidance on resilience to climate change is under development within PIDG’s climate change standard and will be finalised in 2019.

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PIDG Climate Change Classification

Results of Tier Classification Review

19th December 2016

Contents

1. Introduction

This report presents:

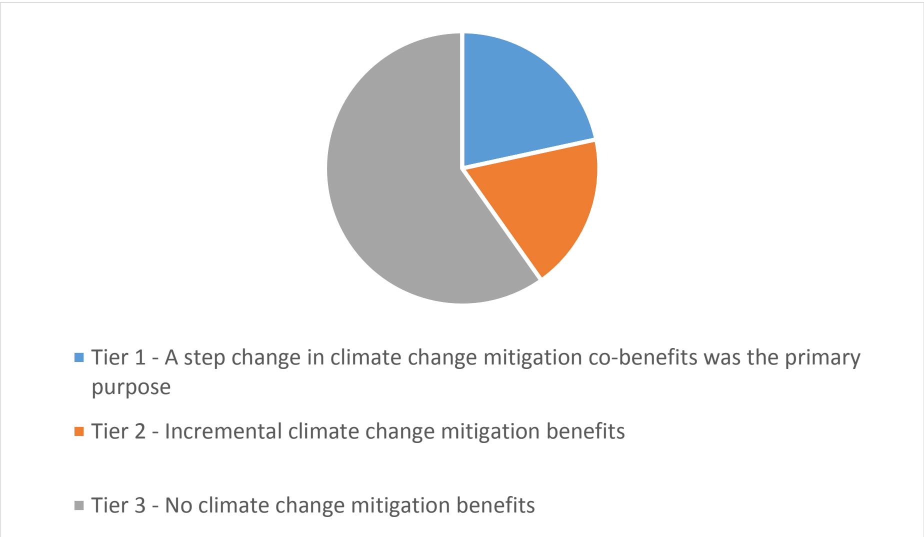
- An update on the report published in 2012 that classified the projects funded by PIDG according to the aims of the respective projects and their associated benefits, i.e. whether they sought to contribute towards climate change mitigation or climate change adaptation.
- The classification of 199 projects has been considered as part of this report. Of those, 170 projects had already been classified as part of the previous report (2012) and 29 were unclassified (15%). One project was previously classified for mitigation but not for adaptation.

2. Climate change mitigation

The results from the portfolio review indicate that:

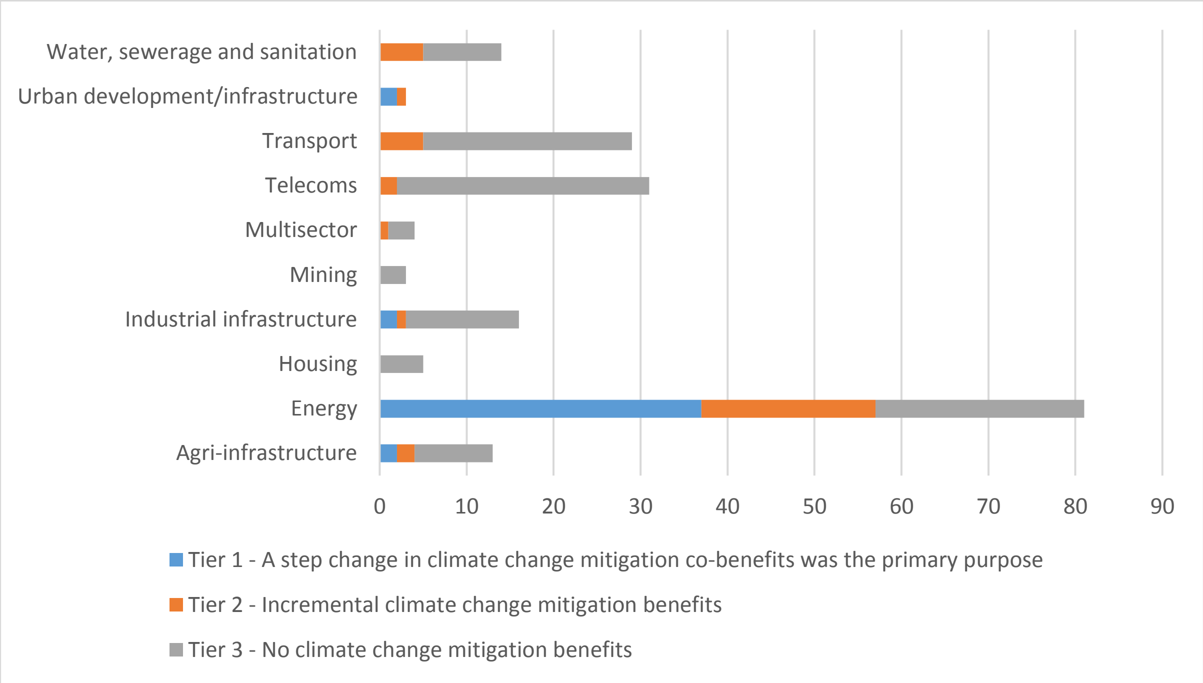
- 22% of projects were classified as having significant climate change mitigation impact and/or including mitigation as the principle objective of the project. These largely relate to renewable energy projects. This compares with a total of 15% of projects classified as having a significant climate change mitigation impact in the 2012 portfolio.
- 19% of projects were classified as having incremental climate change mitigation co-benefits. These include projects where the money has been used to fund public transport systems to alleviate congestion and carbon emissions from cars, for example Transambiental, a project that secures the implementation, operation and maintenance of one of the Transcaribe Mass Transport Integrated Bus System for the city of Cartagena, Colombia.
- 60% of projects had either no climate change mitigation benefits included as part of their objectives, including indirect benefits. This compares with 74% of the portfolio in 2012.
- 9% of the classifications were changed from the last report – most of the ones that were changed were projects that were listed as Tier 2 despite having very minimal climate change mitigation co-benefits, particularly those related to public transport and financing taxis. It was not thought that it was right that these projects be classified as Tier 2 among larger scale projects in renewable energy, for instance, which would be found to have much more impact in terms of saving carbon emissions. We do note that these projects may have significant carbon savings but in these cases there is no evidence provided and indeed it may be that they increase emissions (for example, by replacing walking or cycling).
- In some circumstances, there is no clear evidence that co-benefits for climate change mitigation have been achieved by projects that have been classified as Tier 2. For example, West Bank Solid Waste (588148) does not provide details to support that it is responsible for any savings in carbon emissions to support the classification. In some cases, in particular solid waste projects, emissions savings are implicitly assumed and while we have not changed the tier rating for these (Tier 2) more justification that these are providing emissions savings should be included.

Figure 1: Mitigation classification of projects



A breakdown of these projects across the ten sectors which PIDG operates in is set out below in

Figure 2: Classifications of PIDG funded projects in each sector



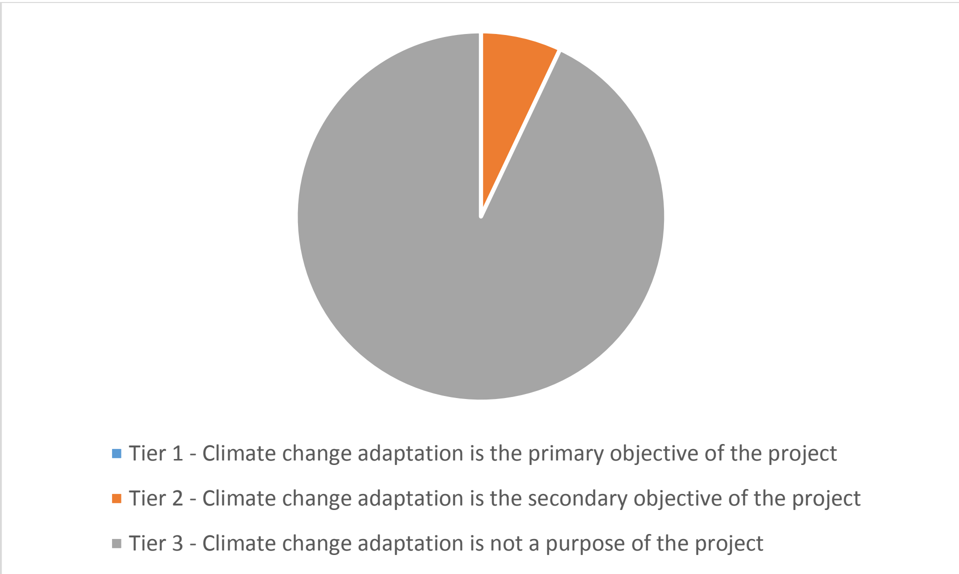
A list of projects that have been classified in each tier is provided in Appendix A.

3. Climate change adaptation

The results from the portfolio review indicate that:

- In the previous report (2012), none of the projects were included as Tier 1 because adaptation was not the clear objective of any of them. Having considered the classifications, this remains the same.
- Several of the projects led to adaptation co-benefits and were therefore classified as Tier 2, often where the projects were looking to achieve climate change mitigation impacts. 7% of projects were classified in this way.[1]
- 93% of the projects have been classified as Tier 3 because they were assessed to not have adaptation as part of their purpose nor achieve any co-benefits – this is even though some of projects that were classified as Tier 3 clearly have a positive impact for resilience, for example through food or energy security. This exposes a challenge with the methodology for the current classification definitions do not recognise resilience as a co-benefit of a project, instead focusing on the extent to which adaptation is included as an objective.[2] An example is the project entitled 'Small Town's Water Program,' which is in Uganda looking to secure access to safe water supply in urban areas – a problem that is likely to worsen as the effects of climate change are further felt in the region. Despite the obvious benefits of the project, it was still classed as a Tier 3 because adaptation was not a purpose of the project. By using the current methodology, the positive impact of this project is therefore missed in any evaluation.

Figure 3: Adaptation classification of projects



The 12 projects that were classified as Tier 2 projects fall across different sectors: Agri-infrastructure (2), energy (5), housing (3), industrial infrastructure (1), and transport (1).

[1] Four were in the last report (2012)

[2] 95% in the last report were classified as Tier 3. It was acknowledged in the last report that, seeing as how the majority of projects were focused on the poor, many will have adaptation co-benefits but the impacts were considered too remote and indirect to warrant anything above a 3.

4. Conclusions

Given the amount of information that is available on each of the projects as part of their descriptions, the purpose of each project is difficult to verify. It is also difficult to distinguish whether the respective projects were classifying themselves based on the purpose of their projects or the expected impact – a blurred distinction, particularly when it came to determining whether or not it was right that a project was classified for Tier 1 or Tier 2 for climate change mitigation.

A significant proportion of the projects that were designed to have climate change mitigation are from the energy sector and the majority of those that are expected to have adaptation co-benefits are from the housing sector.

The classification system for adaptation does not recognise where a project was looking to install resilience and so some of the projects that would be looking to have a positive impact against climate change challenges have not been reflected here.

By focusing on the purpose of each project from the outset the classification system could be used to encourage further practice in this area.

Appendix A: Table of tier classifications results

IV_IDNo	Project	Climate Change Mitigation	Climate Change Adaptation
812	Albania KESH (25624)	3	3
815	Divestment of GoK Share of SafariCom	3	3
816	Privatisation of TelCom Kenya Ltd. (TKL)	3	3
817	Joint Concession for Kenya Railways and Uganda Railways (11615)	2	3
818	AES-Sonel	3	2
819	Bugoye Hydro Power Plant, Uganda	1	3
822	Privatisation of TELECO, Haiti (26250)	3	3
823	Liberia Power Sector Advisory (25742)	3	3
826	Madagascar PPP in the Port of Tamatave (22167)	3	3
827	Development of the Moatize Coal Mine (22694)	3	3
828	Mobile Systems International Cellular Investments Holdings BV (MSI) Expansion	3	3
829	MTN Nigeria Communications Ltd, Nigeria	3	3
830	Moma Titanium Mineral Projects, Mozambique	3	3
833	Eleme Petrochemicals Ltd, Nigeria	3	3
835	Celtel Nigeria Telecoms Project, Nigeria	3	3
837	Seacom, Africa Regional	3	3
838	Safal Investments Mauritius Limited Financing, Africa Regional	3	3
839	Kalangala Infrastructure Services Project, Uganda	3	3
840	Kpone Independent Power Project, Ghana	3	3
841	Geometrics Power Aba Ltd, Nigeria	3	2
842	Chiansi Irrigation, Zambia	3	2
843	Antara Cold Storage Project, Vietnam	3	3
845	Wind Farm Extension Project, Cape Verde	1	3
847	Celtel Kenya Refinancing	3	3
848	Safal Roofing - Mabati Rolling Mills, Kenya	3	3
849	Celtel Chad Financing	3	3
850	Calcom Cement	3	3
852	Joint Venture Partnership in Polynesian Airlines, Samoa (21483)	3	3
854	SPUG I, Philippines (Tablas Romblon and Marindique) (23282)	2	3
855	SPUG II, Masbate, Philippines (23282 Same ID as SPUG I)	2	3
856	Small Towns Water Programme, Uganda SSIP (560987)	3	3
862	SPUG Basilan, Philippines (26153)	2	3
930	Rabai Power Ltd.	3	3
935	Cotonou Port, Benin (26544)	3	3
938	South Asia Energy Management Systems (SAEMS) Hydro Stations	1	3
948	Celtel Africa Telecoms Project - DRC	3	3
949	Celtel Africa Telecoms Project - Madagascar	3	3
950	Airtel Malawi (Former Celtel) Telecoms Project - Malawi	3	3
951	Celtel Africa Telecoms Project - Sierra Leone	3	3
952	Celtel Africa Telecoms Project - Uganda	3	3

953	Shriram Transportation I, India	3	3
954	Olkaria III	1	3
955	Ashta IPP, Albania (25031)	1	3
956	Central Java IPP, Indonesia (26215)	3	3
968	New Cairo Wastewater Project, Egypt (552647)	3	3
971	Wataniya Telecoms, West Bank	3	3
972	Safal Roofing - ALAF, Tanzania	3	3
973	SPA Maghreb Tubes, Algeria	3	3
974	Aldwych Corporate - Project Development Loan	2	3
981	Punjab Silos, India (28159)	3	2
990	Zain Ghana	3	3
991	Chanyanya Pilot Irrigation Project, Zambia	3	3
994	Maldives PPP - Solid Waste Management (28082)	3	3
996	Niger Dry Port, Niger (28148)	3	3
998	Ackruti City Ltd Slum Redevelopment, India	3	2
999	Tina River Hydro IPP, Solomon Islands (28681)	1	3
1005	African Foundries Limited, Nigeria	1	3
1006	Helios Towers, Nigeria	2	3
1010	Cai Mep Port, Vietnam	3	3
1012	Muchinga Power Company, Zambia	1	3
1014	Metro Clark Bulk Water Project, Philippines (29292)	3	3
1015	Kosovo KEK (29107)	3	3
1017	ALAF, Tanzania	3	3
1018	Calidda, Peru	3	3
1027	Ackruti City Ltd Slum Redevelopment, India	3	2
1028	INA Industrija Nafte, d.d., Croatia	2	3
1029	Shriram Transportation II, India	3	3
1030	South Africa Development Finance Company	3	3
1032	Kigali Bulk Water Supply Project, Rwanda (30061)	3	2
1033	Kalangala Renewables, Uganda	1	3
1034	Spencon, Uganda, Kenya & Tanzania	3	3
1035	Housing Finance Guarantee Africa (HFGA), SSA	3	3
1037	Dakar Container Terminal, Senegal	3	3
1038	O3b	3	3
1039	Cai Lan Port, Vietnam	3	3
1044	South Africa Development Finance Company	3	3
1049	Addax Bioenergy (SL) Limited (Addax), Sierra Leone	1	3
1050	Addax Bioenergy (SL) Limited (“Addax”), Sierra Leone	1	3
1051	Tower Power Abeokuta Limited, Nigeria	3	3
1058	Rift Valley Railways (RVR)	2	3
1062	Aeroport International Blaise Diagne, Senegal	3	3
1063	Rajasthan street lighting, India (585107)	2	3
1064	Lesotho Wind Power PPPs (585328)	1	3
1066	Kumar Urban Development Ltd (KUDL) Slum Redevelopment, India	3	2
1067	Tower Aluminium Group Limited, Nigeria	3	3
1068	Zain Iraq	3	3
1069	KivuWatt Ltd., Lake Kivu, Rwanda	1	3
1075	Nyagak III, Uganda (586287)	2	3
1076	PPP for Rural Water Supply, Benin (585927)	3	2

1077	West Bank Solid Waste (588148)	2	3
1078	Bhubaneswar PSL - Street lighting, India (589387)	1	3
1079	Orissa SWM, India (587127)	2	3
1080	South Asia Energy Management Systems II (SAEMS)-Nyamwamba Hydro Station	1	3
1081	Helios Towers, Tanzania	2	3
1082	Kalangala Infrastructure Services Project, Uganda	3	3
1083	Kalangala Renewables, Uganda	1	3
1084	Kalangala Infrastructure Services Project, Uganda	2	3
1085	Kalangala Renewables, Uganda	1	3
1087	Nyadi Hydro Power Project, Nepal	1	3
1088	Kabeli A Hydro Power, Nepal	1	3
1106	Cambodia Salt Farm Development, Cambodia	3	3
1110	TL Port PPP, Timor Leste (596787)	3	3
1113	TICO Takoradi Expansion Project, Ghana	2	3
1114	Bikaner Mechanised Grain Market Infrastructure Development Project, Rajasthan, India	3	3
1115	Takoradi International Company Ltd, Ghana	2	3
1116	PowerGrid Corporation of India (PGCIL)	3	3
1121	Sri Lanka Waste Management Project	2	3
1122	SPA Maghreb Tubes, Tunisia	3	3
1123	Azito Energie Expansion, Cote D'Ivoire	2	3
1124	Coc San Hydro Power Project, Vietnam	1	3
1125	Ethiopian Airlines	3	3
1126	Gul Ahmed Wind, Pakistan	1	3
1127	Ethiopian Airlines	3	3
1128	Metro Power Wind, Pakistan	1	3
1129	Kampala Waste Management PPP, Uganda (595827)	2	3
1131	Cameroon Telecommunication Limited (CamTel)	3	3
1134	Kaluworks Limited, Kenya	3	3
1135	Sendou Power Plant, Senegal	3	3
1136	Thimphu Parking PPP, Bhutan (599164)	3	3
1137	Indorama Eleme Fertilizer & Chemicals Ltd (IEFC)	3	3
1138	Au Financiers Ltd, India	3	3
1139	CASA-1000 (593647)	2	3
1148	Mozambique Water PPP 2 ID (599406)	3	3
1149	Odisha Rooftop Solar Project, India (599407)	2	3
1153	Odisha Rice Storage Project, India (599904)	3	3
1154	Odisha Affordable Housing - Berhampur city, India (593087)	3	3
1171	Liberia Power Amended Management Contract (595547).	3	3
1176	Pakistan Mobile Telecommunications Limited (Mobilink), Pakistan	3	3
1179	Softlogic Finance, Sri Lanka	3	3
1180	Guinea Power PPP, Guinea (600130)	3	3
1189	Helios Towers, Congo (D.R.)	3	3
1190	Quantum Terminals Limited (QTL), Ghana	2	3
1191	SA Taxi Development Finance Proprietary Ltd (SATDF) II	3	3
1194	Lao Roads PPP (600156)	3	3
1195	Gigawatt Solar Power, Rwanda - GRANT DATA CONFIDENTIAL	1	3
1201	Kampala-Jinja Expressway PPP, Uganda (600074)	3	3

1202	Myingyan IPP, Myanmar (600181)	3	3
1203	Bihar Grid, India (600135)	3	3
1204	Smart Energy Solutions	3	3
1205	Helios Towers Tanzania (Vodacom Tower Project)	3	3
1206	Ciprel Expansion, Cote D'Ivoire	2	3
1223	MP Wind Re-Powering Project, India (600176)	1	3
1224	Thai Biogas Energy Company (TBEC), Thailand	1	3
1232	Tobene Power, Senegal	3	3
1233	Fula Rapids, South Sudan	1	3
1235	Odisha Street Lighting Program, India (600371)	1	3
1238	Kenya Power & Lighting Company Ltd (KPLC), Kenya	3	3
1239	Riley Packaging, Uganda	1	2
1240	Zenith Bank PLC, Nigeria	2	3
1241	Rack Centre, Nigeria	3	3
1242	Kpone Independent Power Project, Ghana	3	3
1243	Kota Mechanised Grain Market Infrastructure Development Project, Rajasthan, India	3	3
1244	Seven Energy (7E), Nigeria	3	3
1245	Coc San Hydro Power Project, Vietnam	1	3
1251	Azura Power West Africa Limited (Azura)	2	3
1252	Azura Power West Africa Limited (Azura)	2	3
1253	Cameroon Telecommunication Limited (CamTel) II, Cameroon	3	3
1254	Fatima Fertilizer Company Limited, Pakistan	2	3
1255	Nyumba Ya Akiba Cement project, Democratic Republic of Congo	3	3
1259	Essel Clean Solu, Nepal	1	3
1260	Metro Wind Power	1	3
1261	Zanzibar power, Tanzania (600759)	3	3
1262	Helios Towers, Congo (Republic)	3	3
1263	Helios Towers, Chad	3	3
1264	Lahore Airport, Pakistan (600752) Country Pakistan	3	3
1265	Karadeniz, Multiple countries	3	3
1270	Western Power, Zambia	1	3
1271	Gul Ahmed, Pakistan	1	3
1272	Eaton Towers, Ghana	3	3
1274	Inland Waterways Authority of India (IWAI) Partnership (600931), India	3	3
1278	Siti 1 DI Frontier, Uganda	1	3
1279	HKA, Turkey	2	3
1280	Generadora San Mateo (GSM) and- Generadora San Andres (GSA), Guatemala	1	3
1281	Corbetti Geothermal - PHASE 1 - Ethiopia	1	2
1282	Ghana Electricity Distribution, Ghana (599542) - Phase 2	3	3
1283	Pakistan Power Distribution (GEPCO), Pakistan	2	3
1285	Malawi Water PPP (ID 599358) – Phase 1	3	2
1286	Zambia Solar (601182)	1	3
1290	Moma Titanium Mineral Projects _support facility, Mozambique	3	3
1294	Djermaya Solar - PHASE 1, Chad	1	3
1295	Pavua Hydropower, Mozambique	1	2
1296	Redavia Solar - proof of concept, Tanzania	1	3

1298	African Foundries Limited Expansion, Nigeria	2	3
1299	O3b Expansion	3	3
1300	Plantation et Huileries du Congo (PHC), Congo DR.	2	2
1301	Soroti Solar PV Uganda	1	3
1302	Calcom Cement 2 India Limited ("Calcom"), India	3	3
1303	Quantum Terminals Limited II (QTL), Ghana	2	3
1304	Dakar BRT, Senegal (601344)	2	3
1305	ByCo Oil Pakistan Limited ("BOPL"), Pakistan	2	3
1306	Noha Nyamedjo & Transmar S.A. (NNT), Cameroon	3	3
1307	South Africa Development Finance Company III, South Africa	3	3
1308	Ulendo Road Infrastructure Note Programme, Zambia	3	3
1326	Transambiental	2	3
1328	Mini Hydro Portfolio in North Luzon, Philippines	1	3
1329	Helios Towers DRC – Airtel Tower Acquisition, DRC	3	3
1330	West Bank Buses (599855)	2	3
1347	Lubelia Hydro DI Frontier, Uganda	1	3
1349	Salima Solar, Malawi	2	3

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PIDG Climate Change Classification

Review of Methodology

4th January 2017

Contents

1. Introduction

The Global Sustainability Institute (GSI) at Anglia Ruskin University has undertaken a review of the PIDG climate change classification across its project database. A separate document outlines the results of that review. Additionally a review of the climate change classification methodology has been undertaken. This brief report outlines the recommendations from that methodology review for both mitigation (section 2.1) and adaptation (section 2.2).

In summary the following changes are recommended:

- An update to the definition of mitigation to include a reference to emission savings over a business as usual scenario and quantification of emissions savings in tier 1 of mitigation.
- A new tier 4 classification for mitigation to include projects that may be the subject of future climate change regulations which could materially impact upon their valuation.
- An additional adaptation classification is introduced to differentiate between project resilience and wider community adaptation which results in three classifications as follows:
    - Mitigation
    - Community adaptation
    - Project resilience

With increasing adoption of long term climate policy no project that has a legacy longer than a few years can ignore climate impacts. Therefore, while "*there is a need to ensure that the development-focussed PIDG funds are not relabelled as climate change adaptation funds*" (PIDG, 2012) the methodology for classification should reflect the increasing importance of including risk assessments in all investments. It is with this in mind that we emphasise the climate change classification system should be used as a risk management tool both for PIDG and at the project level during the initiation of projects. Our recommendation for changes to the classification system are based on this hypothesis. We therefore advocate no change to applying the classification to the 'purpose' of the project rather than the 'impact' of the project. However, we note that there is some confusion in the current usage as applied by individual project managers (rather than the methodology as outlined). The classification is occasionally applied to a mix of 'purpose' and 'impact'. We do note that the 'purpose' of a project is not limited to its primary purpose –any climate mitigation impact should be included in the specification of purpose if it is considered during the design and management of assets rather than an additional 'nice to have' impact. This way it is likely the mitigation potential will be optimal and managed.

While we acknowledge the power of quantified metrics (Jones et al., 2016) in helping to achieve the aims and objectives of programmes we do not propose to add quantification to all tier classifications of PIDG with the exception of a measure of emissions saving in tier 1 of the mitigation classification. However, we do suggest that metrics could be explored with investor stakeholders to better understand and align projects with their organisational objectives. This process will also aid in developing a common understanding of the objectives across different stakeholder groups where stated objectives can often be misinterpreted or not sufficiently addressed. We advocate that this process should be conducted separately to the classification implementation.

Investment decision making under future climate change scenarios is not particularly straight-forward, however we recognise that there is increasing attention given to tools and processes that can help. We include some thoughts (section 2.3) on decision making under uncertainty which may be useful in developing recommendations for the management of PIDG projects to ensure they take into consideration future climate risks and resilience.

2. Climate change classification methodology

The following two sections explore the approaches to mitigation and adaptation classification as currently adopted by PIDG, and proposes updates.

2.1 Mitigation classification

The current definition of mitigation as used by PIDG is as follows:

Mitigation implies either reduction in emissions of GHG into the atmosphere or absorption of them from the atmosphere.

However, this current definition fails to capture a vital component of mitigation which will be required if the classification intends to becomes more quantitative in line with current donor demands. We note that this expansion of the definition is already included (PIDG, 2012) in the wider description of mitigation but not explicitly recognised in the definition itself. Therefore, a slight update to the definition is recommended as follows:

Mitigation implies either reduction in emissions of GHG into the atmosphere *relative to a business as usual scenario* or absorption of them from the atmosphere.

The current mitigation classification is:

- Tier 1: Projects whose principal objective is to mitigate climate change and/or whose actions can be considered a step-change in terms of reducing GHG emissions
- Tier 2: Projects where climate change mitigation forms an important part of the project scope and/or where GHG emission reductions are incremental
- Tier 3: Projects that do not have climate change mitigation co-benefits or are only likely to lead to indirect mitigation co-benefits

All these classifications are qualitative at present. However, increasingly many projects, especially those blended with private sector capital, will require reporting in some form or other around quantified emission reductions (see for example, Bank of England, 2015 and ShareAction, 2015). Therefore, for tier 1 projects, and potentially tier 2 projects, it is recommended that the classification methodology includes a quantitative measure of emission reduction over Business as Usual (BaU) potential. In such cases, the assumptions underpinning the BaU scenario/s and their quantification should be disclosed. We acknowledge that this quantification may be very difficult – in particular where assumptions about alternative future investments and energy options may be required, or measuring the emissions from existing (very disperse) energy usage has not been carried out. However, detailed guidelines have already been developed (Green Climate Fund, 2014a) and the multi-lateral development banks are using a toolkit developed by the International Finance Corporation to assess their emissions savings (IFC, 2013). This guidance includes how to calculate baseline emissions for all sub-sectors covered by PIDG including energy, energy efficiency, transport and housing. An excel worksheet is available online (IFC, 2014).

There are many ways to quantify emissions saving such as the indicator set as developed and proposed under the Green Climate Fund (2014b, 2014a) which includes tonnes of carbon dioxide equivalent reduction measures (tCO_2-eq) or as tCO_2-eq per pound (£) invested as a measure of efficiency of investment (Green Climate Fund, 2014b). With a quantification measure included it should be easier to assess the sub-sectors within tier 1 and tier 2 as well as their relative performance. For example, you could achieve higher emissions saving through a behaviour change programme, currently only in tier 2 as an example in Housing Sub-sector (PIDG, 2012), than through a renewable energy system, currently only in tier 1 as an example in Energy Sub-sector (PIDG, 2012).

It is also suggested that when assessing tier 1 or tier 2 an additional consideration could be the 'paradigm shift potential' (Green Climate Fund, 2014b). Notably: does the project provide demonstration potential for a new technology or deployment of a technology in a new geography? Arguably to qualify as tier 1 the ability to act as a demonstrator should be included within the classification. Furthermore, this supports the additionality requirement for PIDG projects.

In addition a new tier 4 is recommended under the mitigation classification. While the majority of projects classed as tier 3 may have little mitigation co-benefits these projects, as well as some in tier 1 and 2, may in fact be 'at risk'. In particular where climate change, or climate change regulation, could be considered material to the future viability or value of an asset but this has not been factored appropriately into the investment decision.

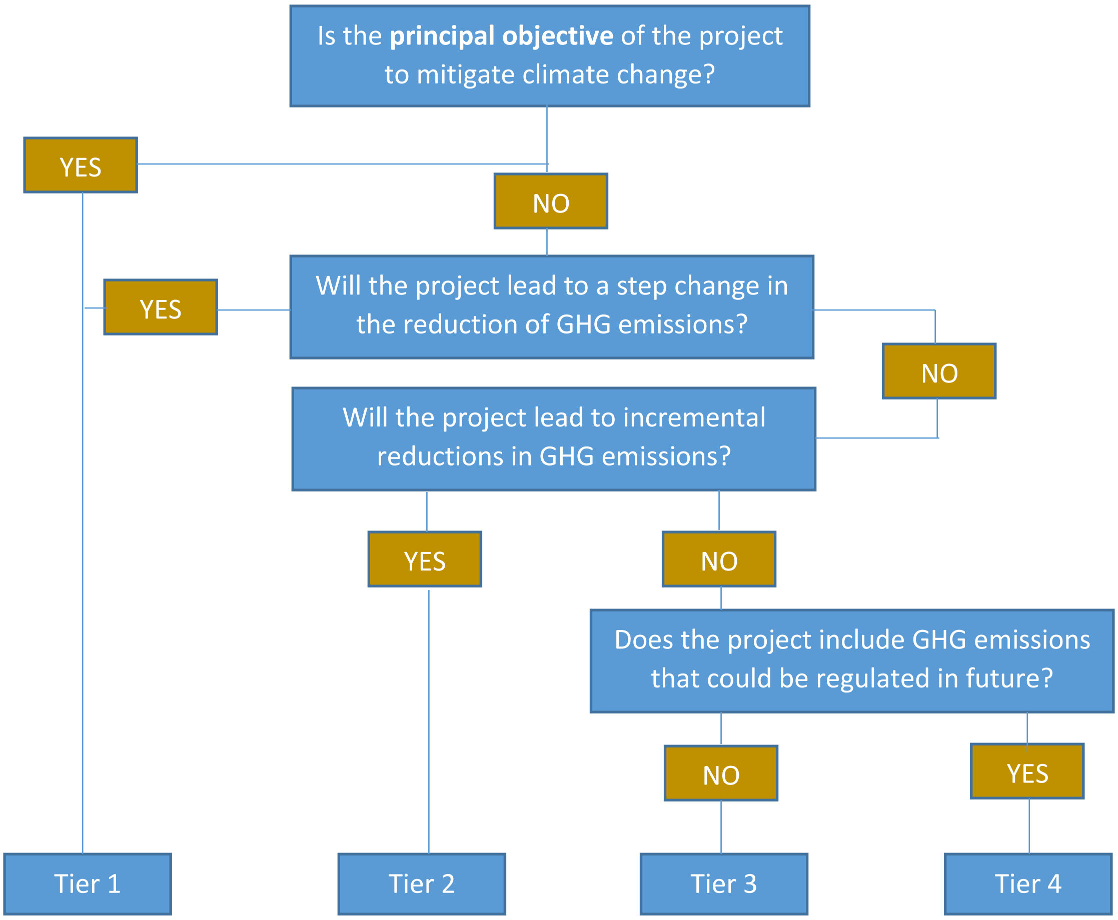
The concept of stranded assets (Carbon Tracker, 2013) is gaining significant traction across the investment community including multi-lateral development banks (Caldecott, 2015). For example, the valuation of any power stations whose primary source of fuel is coal, oil or gas could be materially impacted by future regulation. This regulation could include any international climate agreements, national environmental regulation or international trade agreements. International trade regulations, under the World Trade Organisation, are increasingly subject to discussions focussing on improving the coherence of climate and trade policies (WTO, 2016) and may in future include the concept of embodied emissions.

Of particular note is a recent announcement at the United Nations Conference of the Parties in Mexico by the Climate Vulnerable Forum, which represents 48 of the most vulnerable countries in the world (all PIDG geographies), which commits these countries to be 100% renewable by 2050 (Payton, 2016). As these countries implement policies to achieve this goal the concept of stranded assets may become more material than they are in some developed countries at present.

The proposed mitigation classification is therefore:

- Tier 1: Projects whose principal objective is to mitigate climate change and/or whose actions can be considered a step-change in terms of reducing GHG emissions
- Tier 2: Projects where climate change mitigation forms an important part of the project scope and/or where GHG emission reductions are incremental
- Tier 3: Projects that do not have climate change mitigation co-benefits or are only likely to lead to indirect mitigation co-benefits
- Tier 4: Projects that have GHG emissions which have not been actively considered and which may materially impact the valuation of the asset under future (carbon) regulation

The proposed new mitigation decision tree is:



2.2 Adaptation classification

The current definition of adaptation as used by PIDG is as follows:

Adaptation implies reduction in the vulnerability of human or natural systems to the impacts of climate change and climate variability related risks by maintaining or increasing adaptive capacity and resilience.

The current adaptation classification is:

- Tier 1: Projects whose principal objective is to facilitate adaptation to climate change and climate vulnerability
- Tier 2: Projects where adaptation is a secondary objective and/or are likely to lead to significant climate change co-benefits
- Tier 3: Projects which are not designed to facilitate adaptation to climate change or whose impact is not likely to be significant

Disaster risk management (DRM) has received significant attention in recent years not least through the Sendai Framework (Aitsi-Selmi et al., 2015). At the same time the number of legal and political mandates for incorporating climate change information into decision making is increasing. Therefore, tools and measures for considering DRM in addition to adaptation and resilience at the project and community level are needed (see Appendix A for further thoughts).

There are several methods used to categorise adaptation practice. These include classifications such as research, plan, networks, legislation, awareness raising, implemented change, training, advocacy (Agrawal & Perrin, 2009) or migration, storage, diversification, pooling, market exchange (Tompkins et al., 2010). Additionally standardised quantified measures are being increasingly proposed by a variety of public and private bodies. These quantified measures are still in their early stages of development.

For example, the Green Climate Fund (Green Climate Fund, 2014b) has proposed the following quantified measures for adaptation. In particular those projects that would meet the current Tier 1 classification of PIDG would be captured under the Green Climate Fund and would need to report against these measures.

- *Environmental effectiveness:* including units of human health (disability-adjusted life years (DALYs)) and units of wealth (US$) saved and enhanced;
- *Cost-effectiveness:* US$/DALY and US$ saved;
- *Co-benefits:* US$/unit of co-benefit;
- *Institutional feasibility:* level of acceptance

At present there are limited examples of these metrics in use. Often reporting will refer back to whether particular projects form part of the National Adaptation Programmes of Action (NAPAs) under the United Nations Framework Convention on Climate Change (UNFCCC). The submitted NAPA documents from each country all require some indication of Monitoring and Evaluation (M&E) of adaptation measures including qualitative and quantitative measures. However, there is no consistent approach at present to M&E.

Within their tool to evaluate projects who issue Green Bonds, S&P (S&P, 2016) propose a quantified measure of adaptation or resilience. This measure is the ratio of expected adaptation benefit to investment. The adaptation or resilience benefit is the reduction in combined expected financial, humanitarian and ecological damage (all monetised) over some future climate scenario. S&P would also incorporate their 'view of the adequacy of the third party data and assumptions used to determine the resilience benefit' (S&P, 2016) although they do not detail how this would be measured or combined with the ratio measure.

Given the range of approaches outlined we do not propose that PIDG adopts a quantification measure within its adaptation classification at present.

Within PIDG's current definition of adaptation two aspects are covered but not explicitly differentiated. These are (i) project resilience and (ii) community adaptation. We proposed these two aspects are made explicit by splitting the adaptation classification into two with the following definitions:

Community adaptation implies reduction in the vulnerability of human or natural systems to the impacts of climate change and climate variability related risks by maintaining or increasing adaptive capacity and resilience.

Project resilience implies reduction in the vulnerability of the invested project to the impacts of climate change and climate variability related risks by maintaining or increasing adaptive capacity and resilience.

Additionally, most other classification systems differentiate between building adaptive capacity and building adaptation infrastructure. This difference is implicitly recognised within the definition of adaptation used by PIDG (PIDG, 2012) but is not used in the classification system. We propose this difference be made more explicit in the tier system.

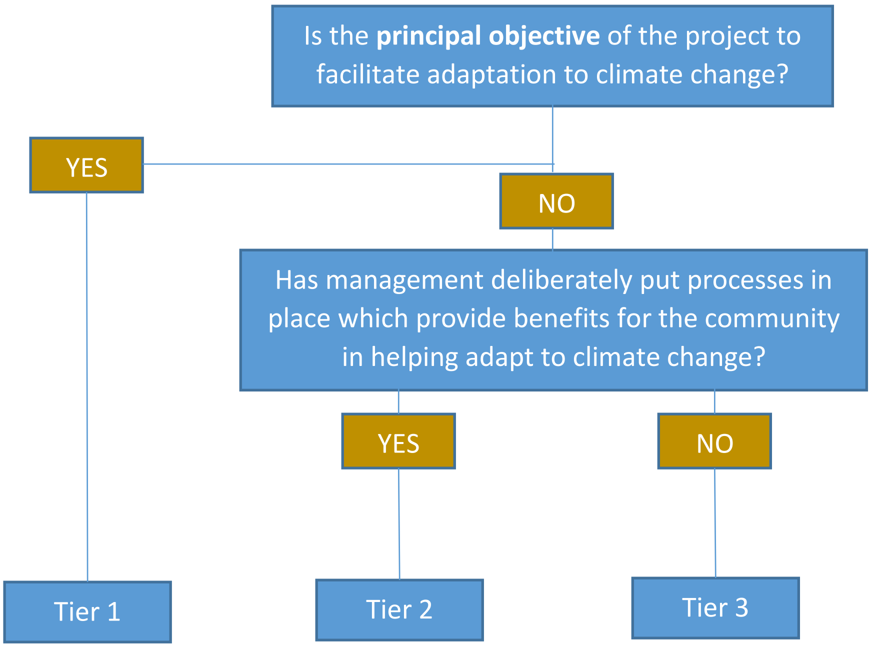
It is proposed the community adaptation and project resilience classifications should both use the same three tiers as follows:

- Tier 1: Projects whose principal objective is to facilitate adaptation to climate change and climate vulnerability (*includes adaptation infrastructure*).
- Tier 2: Projects with a process for management of adaptation to climate change of the community/infrastructure in place (*includes adaptation capacity*).
- Tier 3: Projects which are not designed to facilitate adaptation to climate change or whose impact is not likely to be significant.

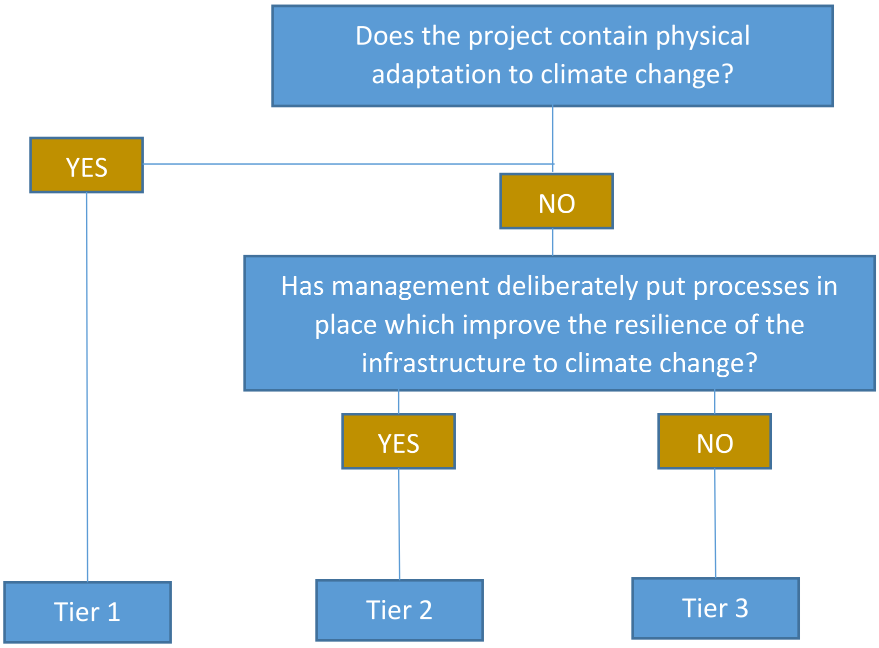
Within the community adaptation classification Tier 2, as outlined above, would include projects where there is no current direct adaptation planned but the management process implemented considers future climate risk and is likely to contribute in some way to the community's ability to adapt to future climate conditions. For example, mobile phone projects, currently classed as having no adaptation, should be included in tier 2 classification where the provision of communications can be demonstrated to be useful in the event of extreme weather or other climate related disasters through the adoption of a disaster risk management plan. Financial savings (if set aside for disaster recovery) could also be considered an adaptation strategy under tier 2.

Within the project resilience classification Tier 2, as outlined above, would include projects where there is no current direct adaptation planned but the management process implemented considers future climate risk and includes resilience measures that allow some adaptation to future climate conditions for the project itself. For example, flexible design of infrastructure to allow retrofit for changing temperatures or port infrastructure that can more easily be raised with sea level increases in the future. The inclusion of climate change related insurance may also be included in tier 2.

The proposed new community adaptation decision tree is:



The proposed new project resilience decision tree is:



2.3 Tools and metrics for decision making under uncertainty

Collectively, socio-economic-environmental uncertainties have the potential to significantly undermine the desired outcomes of PIDG's investment portfolio, particularly in the case of assets which are long-lived or highly dependent on other services/infrastructures which are climate sensitive and/or easily compromised.

For example, where a particular asset is either designed with community adaptation in mind (tier 1) or is particularly vulnerable to climate change, further evaluation of additional quantitative and qualitative performance metrics may be needed. These metrics can be used to objectively compare and as well as individually evaluate the robustness and resilience of current projects and investments, recognising the significant uncertainties underpinning the future evolution of current socio-economic systems, including demographic changes or development trajectories, and the future climate in which they will likely operate.

Ideally, these metrics should be reported as an annual net-benefit projected into the future for the full lifetime of all investments, thus permitting the calculation of investments Net-Present Value or NPV, see HM Treasury (2003) Green Book for full guidance, as well as complementary metrics such as the Internal Rate of Return (IRR) and asset repayment period, in addition to other non-monetary valuation metrics where required. Furthermore, this exercise can be complemented with scenario testing of different options, environmental states and outcomes, thus providing a more robust assessment of current and future viability.

Challenges for decision making under uncertainty include difficulties defining the state space, including the number and range of scenarios to include. To overcome these issues, it is generally advised to include only those variables which the investment is highly sensitive to (for example sea-level rise in the case of coastal flood defences) and including plausible best and worst-case style events to characterise these.

The same level of care is required when specifying the payoff scheme, ensuring to include only those metrics which are decision relevant and ensuring non-monetary and other evaluation criteria are utilised in situations where it is difficult to ascribe economic costs to potential impacts. Lastly, difficulties may arise in the selection and comparison of options. It is generally advised that the analyst includes only those options which are considered feasible, that is an option which does not violate any restrictions specified by the decision makers such as regulatory, budgetary or geographical constraints. Furthermore, the analyst should ensure they fully capture the characteristics of each option, including risk-mitigation strategies, potential for flexible adjustment and adaptive management, lead times and asset life time, as these metrics will be essential in determining overall efficiency and return on investment (Ranger et al., 2010).

In Appendix A, we provide a comprehensive review of current approaches for assessing the potential costs and multiple (net) benefits of PIDG's investment portfolio. While these tools are described from the perspective of assessing measures for adaptation to climate change they can easily be adopted to include metrics of mitigation under future climate scenarios. The requirement to include an assessment of net benefit could be included in future Terms of Reference (TOR) for the Environmental and Social Impact Assessment (ESIA) or any future case study analysis that may be undertaken or commissioned by PIDG.

The following conclusions can be drawn from our review of techniques and tools for supporting decision making under uncertainty listed in Appendix A. Several approaches listed here are directly relevant to PIDG and thus suitable for assessing the robustness and resilience of their current portfolio both to future physical climate change impacts as well as policy changes. Firstly, if probabilistic information is not available and cannot be ascribed to future climate scenarios or policy outcomes then robust methods (e.g. RDM, ROA, Low (no) regret) can and should be used to avoid the likelihood of engaging in maladaptation. Alternatively, analysts who are more interested in achieving 'local robustness' can do so by focussing their analysis on scenarios near their 'best guess' – in which case certain approaches (e.g. Info-gap) may be more appropriate although they are not without their caveats. Robustness can be achieved and measured using various means, including local and global techniques, but also by developing new projects which can accommodate existing (e.g. Low (no) regret) as well as future climate variability. Robust approaches can support the evaluation of the sequencing and implementation of adaptation measures (e.g. ROA), including delaying initial investments until scientific knowledge improves.

It is acknowledged that the delivery and evaluation of infrastructure projects is very dependent on the choice of appropriate evaluation criteria. PIDG already have access to a range of different indicators and we have eluded to several methods including market and non-market techniques for measuring project performance.

With respect to future work, we would encourage PIDG to explore the range of information they currently (and could potentially) collect, combining this with some of the techniques listed here, complemented with a comprehensive review of current projects to identify delivery gaps.

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Appendix A: Decision making under uncertainty

The IPCC defines *adaptation* as the 'adjustment of natural of human systems in response to actual or expected climate stimuli and their effects, which moderates harm or exploits beneficial opportunities' (IPCC, 2007). Conversely, the concept of *maladaptation* is commonly defined as, and may arise in situations when, actions 'lead to increased risk of climate-related outcomes, increased vulnerability to climate change, or diminished welfare now or in the future' (IPCC, 2014). Enterprises engaging in adaptation should consider and evaluate the consequences of their actions, deliberate and inadvertent, as well as review these regularly as scientific knowledge improves to ensure adaptation efforts do not unduly compromise and undermine desired objectives or result in unwanted consequences.

There is now growing recognition of the importance of climate change adaptation in research, practitioner and policy-making communities (Smith et al., 2001). In the last few years we have witnessed a significant increase in the amount of finance available for supporting adaptation, for example the Green Climate Fund in addition to multi and bi-lateral donors, as well as renewed interest from national governments (Preston et al., 2011; Termeer et al., 2012). Previous studies suggest the level of investment required could vary between $25-100 billion over the next 20 years based on a median climate change scenario (Fankhauser, 2009). As the level of funding has increased to satisfy the need for adaptation so has the need for comprehensive method syntheses and adaptation guidance to (i) ensure adaptation is taking place at the right time, in the right place and at the right rate, (ii) diagnose and ensure areas of high risk or significant vulnerability are sufficiently addressed, (iii) enable the effective comparison of adaptation projects in space and time, (iv) ensure resources and support to support adaptation is being effectively utilised and resulting in tangible actions and lastly (v) inform current gaps and deficiencies in research, practice and policy, including governance structures (Pielke et al., 2007; Berrang-Ford et al., 2011; Biesbroek et al., 2013).

A.1 Scenarios

The success of adaptation efforts and projects is closely linked with our ability to predict the future and take anticipatory action to mitigate potential negative impacts. Future socio-environmental systems are characteristically complex and uncertain, resolving trade-offs and anticipating outcomes is made more challenging where there is a lack of scientific knowledge and consensus on the scale and timing of anticipated changes. This is particularly apparent in the context of climate change adaptation and the frequency and severity of extreme events (IPCC, 2014). In these situations, scenarios are increasingly utilised to guide decision making by providing plausible projections of future climate change and its potential impacts. Unfortunately, scenarios are not always provided with a probability of occurrence, nor is this necessarily possible, particularly given the vast uncertainties relating to socio-economic dynamics and some environmental processes such as the impact and rate of methane release from melting permafrost (Schuur et al., 2015). However, scenarios which lack probabilities are incompatible with classical decision theory, sometimes referred to as *decision making under risk* (or utility theory) and alternative evaluation approaches must be sought.

Where probabilities are known and quantifiable, classical decision theory can provide a powerful suite of tools for guiding decision making. In many fields and industrial sectors, it remains the dominant approach for guiding decision making. However, in recent years we have witnessed a steady decline in its popularity due to the recognition that it is largely incompatible with decision making in situations of uncertainty. Unfortunately, evaluating the impact of global environment change on PIDG's investment portfolio would require us to (i) fully describe and quantify the range of future environmental states and their probability of occurrence, (ii) have an in-depth understanding of how different environmental states and actions combine to produce outcomes as well as (iii) have a comprehensive understanding the net-benefits of these potential actions. This can be complicated in situations where these emerge indirectly or due to complex interactions between multiple actors, assets and activities, some of which may be outside of our control. The combination of these factors would demand an extensive reliance on subjective probability assessments over which analysts and decision makers will likely disagree and dispute each other's claims and assumptions - resulting in delay and potentially inaction (Polasky et al., 2011). Thus, we purposefully adopt a *decision making under uncertainty* framing concerning our recommendations relating to PIDG's investment portfolio.

With respect to the scale and temporal resolution of adaptation investment and projects, most climate change impacts are highly uncertain (Ranger et al., 2010). In situations of deep uncertainty, scenario planning, thresholds approach and resilience thinking can provide useful frameworks for thinking about a broad range of future environmental states and hedging investments so they are not unduly compromised or placed at elevated risk from extreme events, sometimes referred to as 'black swans' (Quay, 2010). Furthermore, these types of approaches can prove very useful by helping analysts and decision makers think about key social and environmental feedback effects and threshold boundaries which may negatively affect asset performance. Thus, assessments can be significantly strengthened where multiple stakeholders can contribute to the process by offering their discrete perspectives, methods and evidence, thereby favouring the use of robust, open and inclusive decision tools such as those presented here.

A.2 Decision problem

Decision making under uncertainty can be rationalised using the following decision problem (see Table 1). More advanced decision methods mostly build on this framework by ascribing probabilistic information to the various states of nature, undertaking exploratory scenario discovery, combining stochastic programming and analysis, utilising multi-objective optimisation and/or performing iterative stress-testing of options.

Table 1. Simple decision problem comparing different options and states with various payoffs

	State 1	State 2	State 3	...	State n
Option A	Payoff $_{A, 1}$	Payoff $_{A, 2}$	Payoff $_{A, 3}$		Payoff $_{A, n}$
Option B	Payoff $_{B, 1}$	Payoff $_{B, 2}$	Payoff $_{B, 3}$		Payoff $_{B, n}$
Option C	Payoff $_{C, 1}$	Payoff $_{C, 2}$	Payoff $_{C, 3}$		Payoff $_{C, n}$
...					
Option n	Payoff $_{n, 1}$	Payoff $_{n, 2}$	Payoff $_{n, 3}$		Payoff $_{A, n}$

In the above decision problem, the future climate is described (or discretised) into one or several potential states, each describing a different (but equi-probable) projection of the future climate. The options list the various adaptation projects to be compared and the payoff describes the outcome of each project when exposed to a particular environmental state. States, options and payoffs can be combined with simple decision rules to evaluate the best (or optimum) course of action. The simplest of which, Laplace, involves calculating the average payoff of each option (i.e. Payoff $_{A, 1:A:4}$/n) and selecting the option yielding the largest payoff. Traditionally, these types of assessments have relied on standard economic evaluation criteria (e.g. economic cost and benefits, likelihood of system failures, repayment period etc.), however they can also be combined with non-market evaluation criteria such as improved quality of service, population served or number of beneficiaries served below the poverty line (see PIDGs existing evaluation criteria). Furthermore, these metrics can be combined and weighted using Multi-Criteria Decision Analysis (MCDA) or similar approaches to calculate composite performance metrics (Dodgson et al., 2009) using non-market valuation methods to monetize certain impacts or alternatively eliciting preferences and using these to guide decision making.

Discounting

Many adaptation projects (e.g. hard infrastructure such as coastal defences) are long lived, that is benefits and costs accrue over time in the form of operating and maintenance costs, as well as direct and indirect tangible and non-tangible benefits. To effectively compare different adaptation projects, it is necessary to be able to evaluate the 'present value' of these costs and benefits over the entire lifetime of investments (Ranger et al., 2010). The standard economic method for achieving this is to apply a discount rate (*d*) to costs and benefits, this entails: (i) calculating the expected payoff (*p*) of the adaptation project at each point in in time (*t*), (ii) calculating the discounted expected payoff at each point in time by multiplying *p* by $(1+d)^t$ and lastly (iii) summing the discounted expected payoffs to calculate the NPV of the adaptation project. The notation for calculating the NPV of adaptation projects and investments is thus given as:

$$\text{NPV(i,N)} = \sum_{t=O}^{N} \frac{R_t}{(1+d)^t}$$

Where: N is the total number of time period, d is the discount rate, t is time and R_t is the net benefits (benefits minus costs) at time t

Discount rates are calculated differently depending on the field of study, sector and even the analyst performing the evaluation. For example, the private sector tends to treat the discount rate as the 'opportunity cost of capital', that is its potential value had it been invested elsewhere. Conversely, the public sector traditionally refers to the 'social discount rate' which is calculated using a combination of expected growth rates of consumption combined with some ethical judgments (Ranger et al., 2010). Comprehensive guidance regarding the calculation of appropriate discount rates is available in the Green Book, including the use of declining discount rates where projects are particularly long lived (HM Treasury, 2003). Discount rates are very important as the perceived viability of certain projects is very sensitive to the value of discount rate applied. The exact choice of discount rate is however beyond the scope of the guidance provided here, analysts should instead refer to relevant guidance from their appropriate regulatory body or the Green Book where this is unavailable. In addition to temporal discounting of costs and benefits which accrue over time, analysts can also calculate the distributed costs and benefits of adaptation projects, where these are split between different parts of society. Here and elsewhere referred as equity weighting, this is similarly beyond the scope of the guidance provided here and readers are directed to Pearce et al. (2006) and Boardman et al. (2006) for further details.

Probabilities

The distinguishing feature of decision making under uncertainty is a lack of probabilistic information ascribed to future scenarios. It is thus vitally important here to distinguish between the use of frequentist and Bayesian probabilities. In the case of physical sciences, frequentist probabilities are most dominant – defined here as the observed relative frequency of event occurring based on a long record of empirical observations. For example, the frequentist probability of a coin landing on heads after flipping it 100 times and recording tails 50 times and head 50 times is given as 0.5 or 50%. In contrast, Bayesian probabilities are more regularly defined and interpreted as subjective probabilities, representing the degree of belief in an event occurring. In the above example, we believe the coin has a 50% chance of landing on heads or tails based on our perception of the situation and previous experience. In the case of climate change adaptation, probabilities are almost universally presented as the latter, in practice their calculation requires various subjective judgements to be made regarding the model structure, parameter estimation and the use of empirical observations to constrain predictions (Frame et al., 2005, Solomon et al., 2007, Tebaldi & Knutti, 2007). Due to the reliance on subjective (and sometimes no probabilities) climate change adaptation is almost universally presented as a situation of decision making under uncertainty.

Smith (2007); Stainforth et al., (2007) and others have previously advised researchers and analysts to air on the side of caution when interpreting outputs of climate models in the form of probabilities. The underpinning climate models have previously been shown to be incompatible and inadequate at the temporal and spatial resolution required to make robust adaptation decisions. However, it has also been highlighted that a lack of probabilistic information or perfect knowledge need not be a barrier for adaptation (Dessai et a.l, 2009). The field of decision making under uncertainty has grown significantly in recent years and this is in part due to this recognition combined with the growing accessibility of climate change information in traditionally data poor regions. Various distinctions can be made between decision methods suited for situations where we have access to non-unique subjective probabilities, unique but non-additive probabilities and no probabilities at all. We purposefully limit our discussion to the latter as the others are similarly beyond the scope of our analysis, readers are directed to Kelsey & Quiggin (1992) for a broad overview and Gilboa & Schmeidler, (1989); Allen et al., (2006) and Gilboa, (2009) for a more detailed review of specific techniques.

A.3 Tools and techniques

We provide a review of comprehensive adaptation tools and techniques which can be applied in situations of uncertainty, some of which will be directly relevant to PIDG’s current investment portfolio. These approaches vary in terms of data requirements and their degree of complexity and by extension ease of application (Dessai & Sluijs van de, 2007; UNFCC, 2009; Ranger et al., 2010; Hallegatte & Corfee-Morlot, 2011; Hallegatte et al., 2012; European Commission, 2013). These techniques and approaches should be applied in a cautionary way. If adaptation projects result in systems which are over or under-designed then additional costs can be incurred through residual climate change impacts as well as time and resources needed to adjust these systems in the future (Dittrich et al., 2016). The allocation of resources for supporting adaptation need to be carefully scrutinised to minimise potential costs while maximising potential benefits, the optimal course of action will depend on individual circumstances, data availability and the choice of method applied.

A.3.1 Cost Benefit Analysis

Cost benefit analysis (CBA) is principally based on selecting the option which maximises societal benefits based on potential Pareto efficiency. It is commonly utilised to determine whether a project is financial viable by evaluating all the monetary costs and benefits accrued over its lifetime, represented by its NPV. If the NPV is positive, then it is generally accepted that the project should proceed as planned, if it is negative then the project is normally cancelled or significantly re-structured (Boardman et al., 2014). Calculating the NPV of different projects enables them to be effectively compared against each other on an ordinal scale. General criticisms levelled against CBA relate to the monetization of non-market (or non-tangible) benefits and the choice of discount rate applied. The advantage of CBA is that it can be applied easily and with limited technical resources, furthermore the results are generally appropriate for non-technical audiences, see Escobar (2011) and Willenbockel (2011) for various applications.

A.3.2 Cost Effectiveness Analysis

Cost Effectiveness Analysis (CEA) is generally applied as a direct alternative to CBA. It is commonly used in situations where it is difficult or more controversial to monetise benefits, for example quantifying potential beneficiary socio-economic status or the value of a particularly ecosystem or its derived services. CEA works by comparing alternative (non-mutually exclusive) options in terms of a ratio between their costs and a single quantified, non-monetised 'effectiveness' measure. The optimal course of action is determined based on the least cost optimisation. CEA is relatively easy to apply in practice owing to the simple calculations involved. For example, if the effectiveness of various options is equal then the problem can be rationalised to a simple cost minimisation exercise. CEA is most effective when the benefits of adaptation projects can be measured using the same (or very similar) indicator or are identical. Projects which have a low cost, low impact, but high cost-effectiveness ratio will be generally ranked higher than costly projects with high impacts but a lower ratio. Example applications include Boyd et al. (2006) and Luz et al. (2011).

A.3.3 Multi-criteria analysis

Multi-Criteria Analysis (MCA) is a commonly used technique for comparing options based on a combination of qualitative and quantitative indicators which permits the ranking of alternatives based on user specified weights. Elements which are difficult to assign monetary values such as distributional or psychological impacts can be assigned larger weights by the decision maker. The principal challenge of MCA is linked with the choice of user-specified weights, in complex situations it is not always possible nor appropriate to specify discrete rankings, particularly where there are apparent and significant trade-offs involved. Qualitative and quantitative data included in MCA is measured on an ordinal (as opposed to an absolute) scale thus also preventing the generalisations and transferability of results. Due to its relative simplicity, it can be easily calculated but can also results in prolonged negotiations and disputes over user-weightings depending on individual interest. Example applications include de Jalon et al. (2013).

A.3.4 Info-gap theory

Info-gap theory encompass a range of techniques which provide qualitative information about the robustness of adaptation projects based on a best-guess of the future climate. Its development can be traced back to Robust Decision Making (RDM – see section A.3.6), the key differences being that it produces robustness and opportuneness curves – which together enable the decision maker to ensure potential losses do not exceed a given level. These curves form part of a larger informal decision making process, where the decision maker is able to specify the largest loss they are willing to sustain as well as the smallest windfall they wish to have the possibility of achieving (Ranger et al., 2010), the optimal course of action is then chosen through careful selection using the robustness and opportuneness curves respectively. An essential component of info-gap theory is the choice of the uncertainty model, including how it is defined and measured. The principal disadvantage of info-gap theory is that it requires the analyst to specify their best guess of the future. This can be a very subjective exercise and as such has been criticised for being incompatible for situations of deep uncertainty (Ben-Haim, 2006).

A.3.5 Real Options Analysis

Real Options Analysis (ROA) focuses on achieving robustness through adaptive management by permitting flexible and reversible projects for handling deep uncertainty. The primary concept behind real options is that they can be easily adjusted as new information emerges, enabling projects and assets to keep pace with rapidly changing environments which are characterised by complex interactions and uncertainties. Real options analysis can be originally traced to financial economics, extending cost-benefit analysis to consider new information and iterative learning. ROA works particularly well for large irreversible investments which have long lifetimes, which are climate sensitive and where there is a potential danger for significant over or under-design over time. ROA can expose flexible adaptation strategies, however these are typically characterised by higher up-front initial costs (at least relative to a simple optimal solution). Furthermore, projects ascribing to real options may also require constant intervention during the lifetime, this may not always be possible in the case of privately operated, but publicly owned investments. Example applications include Woodward et al. (2011) and Gersonius et al. (2013), as well as Walker et al. (2001) and Hasnoot et al. (2013) for similar approaches.

A.3.6 Robust Decision Making

Robust decision making (RDM) initially involves specifying the objections and problem constraints of adaptation projects and then performing exploratory analysis to identify the best course of action based on multiple model runs. In RDM uncertain parameters and their plausible ranges are initially quantified, these are then used to evaluate the vulnerabilities of different strategies by producing trade-off curves. Through iterative testing, various candidate strategies can be modelled, evaluated and adjusted. RDM has been predominately applied by the RAND Corporation (see Lempert et al., 2003) and is commonly used in situations where uncertainty is poorly characterised. Advantages of RDM is that it permits the analysis of risks and benefits of potential policies in situations of deep uncertainty, but also permits stress testing of different strategies. The primary disadvantage of RDM is the costs and resources involved. For example, an equivalent RDM study in Southern California required an initial investment of $100,000 (where a simulation model existed) and $500,000 (where no simulation model existed). RDM requires simulation models to be developed, metrics, acceptable risks and benchmarks for comparing strategies to be specified – these can incur a significant amount of time. Example applications include Lempert et al., (2003) and Lempert & Groves (2010).

A.3.7 Low (No) regret solutions

Low (no) regret solutions are perhaps the simplest approach listed here, but they can also be very difficult to identify and evaluate over long time horizons. These options are robust due to their internal characteristics and not because they have necessarily been designed with an optimal future in mind (Fankhauser & Soare, 2013). These options avoid the needs to quantify what the future might look like and what impact it will have, instead they place much greater attention on the immediate social and economic benefits provided, delivering co-benefits and enhancing local resilience (Watkiss & Hunt, 2014). The advantage of these types of approaches is that they can be relatively low cost for example fixing leaky pipes or implementing resource recovery technologies, they also come with the added advantage of being able to show immediately visible benefits. As a result they are generally considered to exhibit best-practice however they can also result in maladaptation if they are poorly conceived or implemented. For example, enhanced irrigation technologies when poorly deployed can actually increase water use and worsen drought conditions.

Furthermore, these types of options are not always immune to black swan style events because future forecasting is rarely undertaken, or at least not to the same level as in the other approaches listed here. The goal of decision making in situations of uncertainty is thus to identify solutions which can deliver immediate co-benefits, which are robust in the short term but are also resilient to sudden shocks as well as long term trends, where these could have significant and cumulative negative impacts.

A.3.8 Robust-utility

The concept of robust-utility, as outlined in the Green Z-score (Green & Weatherhead, 2014), provides a complementary approach to the techniques described here. This decision criterion considers all potential options, states and payoffs but does not necessarily rely on having access to probabilistic information, which is not always available. It is hence amenable with both local and global robustness assessments. If probabilistic information is available or needs to be estimated, then this criterion can be easily combined with fuzzy stochastic programming or similar approaches (see Zeng et al., 2016 for example). The principal advantage of this criterion is the relative ease in which it can be applied, which permits rapid assessment but also generalisations and transferability of results between different decision problems – encouraging learning and capacity building across different stakeholder groups. The criterion can also be applied 'statically' for large infrastructure adaptation projects but also iteratively to encourage adaptive management in line with ROA type approaches. The criterion borrows elements from standard economic evaluation techniques including CBA, CEA and MCA as well as robust methods including ROA and RDM and is purposefully designed to encourage scenario testing and resilience planning.

The various elements underpinning this criterion can also be customised and (if required) exaggerated to reflect extremely polarised risk appetites and attitudes. This is particularly important for assets which are highly sensitive to the climate and particularly critical such as nuclear power plants, hurricane evacuation centres or hydrological pumping stations. Unlike traditional economic models, which commonly assume a single rational model to describe all decision makers, the Green Z-score uses three parameters to generate a simplified rational model that can be personalised for individual risk appetites and different decision problems. The decision model and assumptions underpinning the Green Z-score have been purposefully selected as they place the focus on choice behaviour, enabling decision makers to resolve trade-offs in a transparent, audible and analytically robust manner (Hajkowicz, 2008).

A.4 References

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