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Ranking climate change adaptation options

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Abstract: Failure to adapt to climate change is currently considered one of the major threats affecting humanity. Hence, much effort is being put into discussing adaptation approaches. While many adaptation options have been identified, the academic literature does not present a simple process that local councils and community members can use to rank adaptation options. In this context, community members participating on planning processes are presented with many adaptation options, but with no objective approach for selection, which adds challenge to the planning process. With the objective of addressing this issue, this work proposes a simple equation that allows calculating the applicability level of adaptation options. Results can then be plotted into graphs that allow correlating adaptation options and applicability level, which can be easily understood by community members. To develop such equation, this work built on existing sophisticated models from where the indicators used on the equation were identified, as well as the relationship between them.   A scale was proposed to help on identifying adaptation options that should be implemented on the short, medium and long term, and options that should only be implemented if the circumstance change.

Keywords: climate change, adaptation options, raking system, applicability level.

1. Introduction

In 2019, the World Economic Forum ranked the impacts of climate change and failure to adapt to them as the two most significant threats to humanity [1].   In this context, many local communities are starting to prepare their adaptation plans. To help on this, [2] published a compilation of 80 adaptation options that are suitable to be implemented by local councils, residents and industries. They have not discussed, however, how to prioritize between so many options.

This has been done on the past by other academics. [3], for example, have proposed the use of probabilistic tools, such as Bayesian Belief Networks - BBNs, to correlate adaptation options to different scenarios and, based on this, to identify robust strategies. [4] proposed the use of a complex table that considers six different criteria, which are then combined to estimate the applicability level of each response. Others, such as [5], have limited to describe criteria that should be taken into consideration when selecting best options, yet makes no reference of how to combine the described criteria.

While these approaches are academically valid, they require refined knowledge to be used. Hence, are not appropriate to be used by local community members. [3]'s approach, for example, requires modelling and probabilistic knowledge. [4]'s method, while much simpler than the approach developed by [3], encompasses very large tables, which can be difficult to understand. Just to illustrate, if [4]'s approach were to be used considering the 80 options described by [2], it would have 81 lines (titles plus 80 options), 7 columns and 567 nodes. Hence, if presented to the local community, it was likely to create more confusion than understanding.   Finally, descriptive approaches, such as presented by [5], are useful for other academics trying to understand climate

change adaptation, but add no objectivity to community discussions and decisions about which adaptation options should be implemented first.

The lack of a simple tool to calculate the applicability level of different adaptation options means that, when faced with the challenge of developing a local participatory plan for climate change adaptation, community members are presented with an enormous amount of adaptation options, yet are given limited (and many times biased) guidelines about how to choose between so many possibilities. This work aims at addressing this gap by suggesting a simple process that can be used by local communities and councils to reduce the subjectivity of ranking climate change adaptation options.

More specifically, the objective of this work is to propose a simple equation that can be used to estimate the 'applicability level' of different adaptation options. This will allow adaptation options to be presented to the community in graphs that correlate 'adaptation options' and 'applicability level', which are easily understandable by anyone.

An example of the expected outcome is presented on Figure 1. The blue dots on the Figure 1 represent 43 adaptation options and the Y-axis indicates the applicability level. The lower the applicability level the better the adaptation option. Independently of what the options are, it is easy to learn from this graph that options one to 33 are more 'applicable' than options 34 to 43.
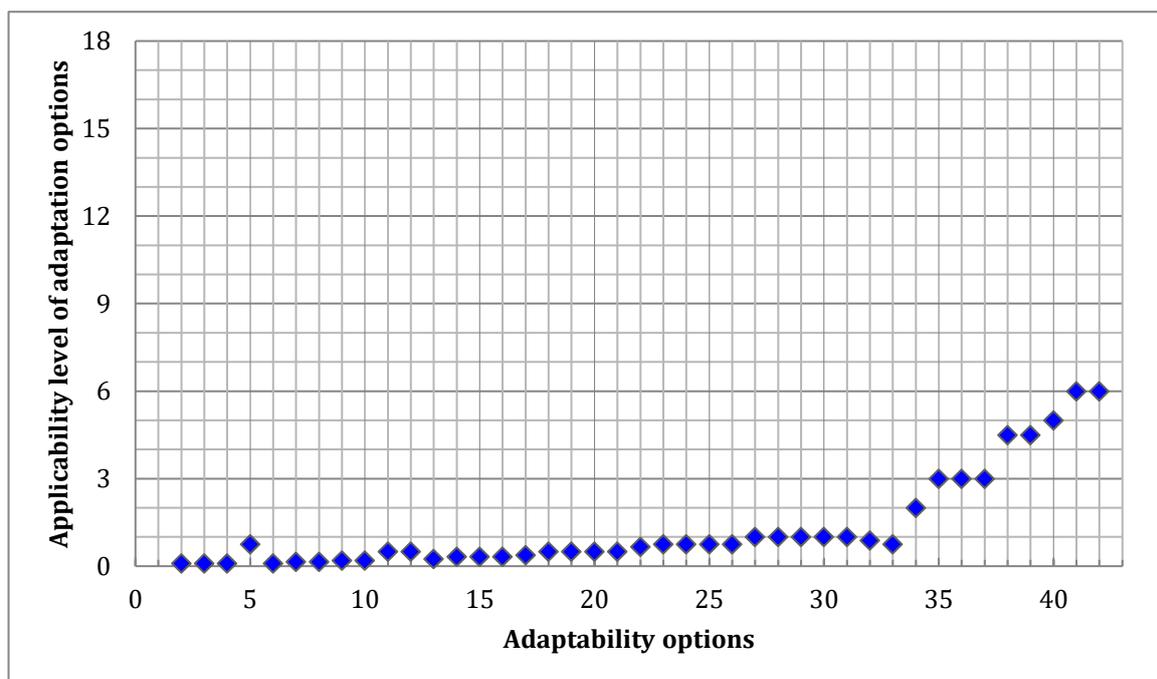

Figure 1. Example of outcome expected from the process here proposed

Applicability level, in this case, refers to whether aspects such as economic, environmental and social costs justify the outcomes of a specific adaptation option. This, of course, is site specific. The costs of the construction of a seawall, for example, maybe justifiable in a place that frequently floods due to storm surges, but might not be defensible on a place that is forecasted to flood, but has not been inundated yet.

2. Materials and Methods

Whereas the previously described approaches do not offer a simple solution for community members to make informed decisions in regards to climate change adaptation, through their work, [3-5] identified eight criteria they deem as important for assessing the applicability level of

adaptation options (these are described in Section 3.1).   For this work, the appropriateness of these criteria as indicators was tested against the characteristics of robust indicators as described by [6-8]. While so, this analysis did not include characteristics cited by [6-8] such as whether the indicator (1) had been previously used, (2) is culturally appropriate and (3) is acceptable by those who will use the data analysis, because, in one hand, all criteria derived from the literature, hence were previously used, and, on the other, culturally appropriateness and acceptability depends on the communities that will eventually use them, and this is unknown on the moment.   Criteria presented by the literature that failed to comply with characteristics of robust indicators were reworded. States for each of the proposed indicators were presented as well as their values and related elucidations. This is presented in Section 3.2.

Based on the criteria described by the literature and deductive logic, three assumptions were established. These were used to define an initial equation, which was first used to calculate minimum and maximum values of applicability level. Best and worst case scenarios were used for this task. This is presented on Section 3.3.

The equation was, then, tested on two case studies. The first case study is based on a real example: the Sunshine Coast region (Australia), which is where this study was conducted. The second case study is fictional.   It was based on the Sunshine Coast, but it pretends that the area is already facing problems with storm tides and bush fires, which are frequently threatening lives and properties.   Description of vulnerabilities affecting the case studies is presented in Section 4.

The applicability level of ten adaptation options was estimated to both case studies. Adaptation options used for testing the equation were: education and public awareness, community participation, warning systems, hazard reduction burns in fire-prone natural areas, shutters and sprinkler systems, protection of natural systems and reafforestation of areas close to waterways, construction of seawalls, multistorey building with the lower level planed as non-living areas, limiting life of houses to minimise financial outlay and planning and legislation. It was considered that three different plans were developed for each case study, each based on different average temperatures increase. Temperatures increase considered were 1.5°C, 3°C and 5°C. Results were used to discuss the suitability of the proposed equation (Section 5).

3. Developing the equation

3.1. Criterion from the literature

[3-5] identified eight essential criteria for assessing the applicability level of adaptation options. These are (Table 1):

• Uncertainty, which is considered the central issue of the adaptation discourse. This is because while the scientific community largely agrees with climate changes theories, there is still a lot of imprecision related to how much the temperature will change until the end of the present century. This is partly due to the complex ecological functioning of our planetary ecosystem and our limited understanding of the feedback processes involved on climate regulation, which, of course, compromises the development and the results of existing models. Yet, this is just part of the problem.   The main challenge is to forecast how humanity will address the issue of diminishing the emission of greenhouse gases.   So far, despite the existing agreements, the emission of greenhouse gases is still significantly increasing [9] and, considering the political discourses of key countries such as the US and Brazil, it is likely this pattern will continue in the years to come. Under this uncertain response of humanity, according to the IPCC and the U.N. World Meteorological Organization, the global average temperature is likely to increase between 1.5°C (best-case scenario) to 5°C (worst-case scenario) [10-11].

• Costs, which is probably the most obvious parameter for evaluating the applicability level of any adaptation option, because the implementation and maintenance costs of some responses, such as the construction of a seawall, may be higher than the total budget for adaptation.

• Decision-making time horizons, which, according to [5], is important because some adaptation options may already be in process of implementation or, on the contrary, may significantly impact the existing development plans. According to [4], this maybe an option to reduce uncertainty and corresponding costs.

• Synergies between strategies and co-benefits were used to refer to the capacity of options to mitigate risks affecting multiple sectors. The restoration of coastal dunes, for example, may be implemented to avoid flooding, yet it is likely to positively affect the local environment and landscape as well. Such improvements may further influence local economy, through tourism e.g., and society, by the expansion of areas for leisure.

• Conflicts between strategies, which is used to refer to negative impacts of adaptation options caused to different elements than the ones they were projected to protect. This would be the case of, for example, the construction of a seawall to help on mitigating flooding, which will negatively impact the local ecosystem.

• Reversibility, which is used to assess whether adaptation options can be removed in case climate change is less significant than forecasted or does not take place.   Options such as restriction of future construction on areas prone to flood can be easily cancelled if flooding does not take place; hence it is a reversible option.   [4] would also classify this option as a soft-strategy, which includes all institutional and financial tools, which, by default, are always reversible. Reversibility, however, is not always relevant.   Adaptation options, such as restoration of coastal dunes to avoid flood, for example, can be reversed, but should not, because reversion would cause negative impacts. Reversibility, then, is only relevant if the implementation of the adaptation option caused negative impacts.

• Flexibility, which refers to the capacity of an adaptation option to be upgraded in case climate change is more intense than expected. Flexibility, however, is not likely to be important when planning is based on 5°C increase on average temperature, because it is unlikely temperature will increase more than that.

• No-regret, which is used to assess the value of options in case climate change does not take place. While it is highly unlikely climate change will not occur [11], this scenario allows analysing the value of adaptation options in the present.   Adaptation options that have negative impacts and no immediate benefits are considered regrettable by [4,5].   This would be the case, for example, of construction of a seawall at a place where flooding still does not occur, as it will have no value if climate change does not occur and, yet, would negatively impact the local environment. On the other hand, restrictions on constructions on areas prone to flood would be considered by [4,5] as a no-regret option, because it can easily be cancelled if time shows this adaptation option is not necessary.

Table 1. Criteria identified by the literature correlated with characteristics of robust indicators

Indicators \ Criteria	Observable	Simple to interpret	Measurable	Cost-effective in terms of data collection, analysis and interpretation	Able to be collected, analysed and reported on a timely fashion	Applicable in different settings	Relevant	Neutral	Open for the inclusion of unexpected aspects	Valuable within the set of indicators
Uncertainty						x	x	x	x	x
Costs	x	x	x			x	x	x	x	x
Decision-making time horizons	x					x	x	x	x	x
Co-benefits	x	x	x	x	x	x	x		x	x
Conflicts between strategies	x		x			x	x	x	x	x
Reversibility	x	x	x	x	x	x	x	x	x	x
Flexibility	x	x	x	x	x	x	x	x	x	x

No-regret		x		x	x	x	x		x	x

3.2. From criteria to indicators

Table 2 presents on a synthetised form correlations between the described criteria and characteristics of robust indicators (as defined by [6-8]).   All criteria were considered valuable in the context of accessing the applicability level of adaptation options, yet only 'co-benefits', 'reversibility' and 'flexibility' fulfill all the requirements to be used as indicators. All other criteria had to be reworded.

Table 2. Criteria, indicators, states, values and observations

Criteria	Indicator	States	Values	Observations
Uncertainty	Scenario	1.5^{O} C 3° C 5° C	N/A	The state of this indicator relates to the average temperature increase used for planning.
Costs	Costs	Low	1	Costs associated with precisely calculating the price of certain responses, such as construction of a seawall, may be prohibitive during preliminary studies. To avoid this obstacle, 'costs' can be, at this stage, a subjective measurement calculated in comparison to other responses.
		Moderate	2	
		High	3	
Decision-making time horizons	Timing	Urgent	0.1	If the implementation of the adaptation option can avoid life threatening situations.
		Convenient	1	When the implementation of the adaptation option is not urgent, but is in synchrony with ongoing development.
		Inconvenient	2	Implementation of the adaptation option is not urgent and may significantly impact the existing development plans.
Co-benefits	Co-benefits	1 to 5		The elements that can be influenced by an adaptation option are likely to be case specific, but examples of elements that maybe co-benefitted include properties and infrastructure, natural systems, food production, availability of water, and well-being of the local population. State of co-benefits equals the number of elements being co-benefited by the implementation of the option.
	Cascading effect	Yes	2	Adaptation options, such as raise public awareness, have no immediate co-benefits. Yet, may influence people to voluntarily implement other responses, such as installation of solar panels.
		No	1	
Conflicts between strategies	Negative impacts	Not significant	N/A	While some adaptation options negatively impact elements different than those they were planned to protect, others negatively impact the elements they were designed to protect; e.g. limiting life of houses to minimise financial outlay will on the long run increase the costs associated with house maintenance. The indicator 'negative impact' includes both sorts of impacts.
		Significant		
Reversibility	Reversibility	Not relevant	N/A	If the implementation of the adaptation option caused no significant negative impact.
		Reversible	N/A	If the adaptation option can be removed or

		Irreversible	N/A	cancelled without significant economic or ecological costs. If the adaptation option cannot be removed, or removal would have significant economic or ecological costs.
Flexibility	Flexibility	Not relevant	N/A	If the adaptation option was planned to efficiently respond to 5oC temperature increase.
		Flexible	N/A	If the adaptation option can be improved to efficiently respond to real future needs.
		Not flexible	N/A	If the adaptation option cannot be improved to efficiently respond to real future needs.
No-regret	Level of regret	Low	1	Reversibility not relevant & Flexibility not relevant Reversibility not relevant & Flexible Reversible & Flexibility not relevant Reversible & Flexible
		Moderate	2	Reversible not relevant & Not flexible Reversible & Not flexible Irreversible & Flexibility not relevant Irreversible & Flexible
		High	3	Irreversible & Not flexible

The reworded indicators are: scenario, costs, timing, co-benefits, cascading effect, negative impacts, reversibility, flexibility and level of regret. These are presented on Table 2 along with their possible states, values and elucidations of how to measure each indicator.

3.3. The equation

The equation was proposed based on the following assumptions:

1. 'Timing' is the determinant factor in situations that involve life and death situations.
2. 'Number of co-benefits' and 'cascading effect' indicate potential positive aspects.
3. 'Costs' and 'level of regret' indicate the potential negative aspects.

Therefore,

$$\text{Applicability level} = \text{Timing} \times \frac{\text{Costs} \times \text{Level of regret}}{\text{Co-benefits} \times \text{cascading effect}} \tag{1}$$

Using this equation and the described values, values of 'applicability level' can vary between 0.01 and 18 (Table 3). The smaller the 'applicability level the more appropriate the adaptation option is.

Table 3. Possible values of 'applicability level'

Indicators	Best case		Worst case	
Timing	Urgent	0.1	Not urgent	2
Costs	Low	1	High	3
Co-benefits		5		1
Cascading effect	Yes	2	No	1
Reversibility	Reversible		Not reversible	
Negative impacts	Not significant		Significant	
Flexibility	Flexible		Not flexible	
Scenario	5o C		1.5o C	
Applicability level		0.01		18

4. The case studies

The Sunshine Coast is located in the south-east of the state of Queensland, 105km (about 1.35hrs via the M1) north of Brisbane.   Its coastline extends for about 50km.   It covers an area of 1,633km² and in 2016 had a population of about 250,000 people [12].   According to [13], by 2100, climate change is likely to affect the Sunshine Coast region in the following ways:

- Sea level rise and more intense and frequent storms and storm surges can be expected to damage infrastructure, including commercial and residential buildings, access roads, the local Private Hospital, schools, airport and police stations.   Impacts are likely to be more significant in low altitude areas. However, intense storm activity may exacerbate erosion and the occurrence of landslips.
- Sea level rise is expected to flood farmlands.   This may affect the availability of food.
- If sea level rises by 2.5m, then urban areas are also expected to flood, as are forested areas.
- Increased frequency and intensity of droughts are likely to intensify bushfires, increasing the vulnerability of buildings and local flora and fauna.
- Acidification of the ocean and decrease in oxygen levels of marine waters are likely to affect local fisheries and coral reefs, which may affect food availability.
- While local dams are not likely to be directly affected by sea level rise (+0.74m and +2.5m), decreased frequency of rain may cause scarcity of potable water and hamper farming activities.
- Loss of pollinators (e.g. bees, birds and bats) may also hamper farming activities.
- Temperature increase and storms may cause discomfort to the local population, especially the elderly, increase the vulnerability of houses to fire and decrease the water quality of local dams.

4.1.   Differences between case studies

For case study 1, in the present, there are no live and death threatening situations. Flooding and bush fires do occur, but are manageable. In case study 2, which is fictional and based on Case study 1, flooding and bush fires occur periodically, causing destruction of infrastructure and death.

5. Testing the equation

5.1. Initial data

Ten adaptation options were used to test the equation. Table 4 synthetises the data imputed. The adaptation options that were tested are listed in the first column. The second column 'timing' is subdivided into two piers, one for each case study (C1 & C2). The last column, 'level of regret' is subdivided into three piers, one for each scenario (1.5^O C, 3° C and 5° C). The values included in these columns were estimated accordingly to Table 4.

Table 4. Data used to test the equation

Adaptation options	Timing		Costs	Co-benefits	Cascading effect	Negative impacts	Reversibility	Flexibility	Level of regret		
	C1	C2							1.5^OC	3^OC	5^OC
1. Planning and legislation	1	0.1	1	5	2	0	NR	1	1	1	1
2. Hazard reduction burns in fire-prone natural areas	1	0.1	1	4	1	0	NR	1	1	1	1
3. Shutters and sprinkler systems	1	0.1	1	4	1	0	NR	1	1	1	1

4. Protection of natural systems and reafforestation of areas close to waterways	1	0.1	2	5	1	0	NR	1	1	1	1
5. Education and Public awareness	1	1	1	1	2	0	NR	1	1	1	1
6. Community participation	1	1	1	1	2	0	NR	1	1	1	1
7. Warning systems	1	0.1	1	1	1	0	NR	1	1	1	1
8. Construction of seawalls	2	0.1	3	5	1	Y	i	2	3	3	2
9. Multistorey building with the lower level planed as non-living areas.	2	0.1	3	2	1	Y	i	2	3	3	2
10. Limiting life of houses to minimise financial outlay	2	2	3	1	1	Y	i	2	3	3	2

Where: NR stands for Not relevant.   In the column 'negative impacts': 0 refers to not significant impacts and Y to significant impacts. In the column 'reversibility': i stands for irreversible. In the column 'flexibility', 1 refers to potentially flexible and 2 to potentially not flexible (depending on scenario used for planning).

It was considered that the value of 'costs', 'co-benefits', 'cascading effect', 'negative impacts', 'reversibility', 'level of compromise' and 'flexibility' remain stable independently to the case study or scenario tested. The value of 'timing' was altered to indicate that in the context of case study 1 there are no life threatening situations. Hence, timing was considered to be 'convenient' to all options, except construction of seawall, multistorey building with the lower level planed as non-living areas and limiting life of houses to minimise financial outlay, which were considered 'inconvenient' as they significantly impact the existing development plans.   The values of education and public awareness and community participation are the same for case studies 1 and 2, as they were considered to not alleviate the life and death threats that characterize case study 2.

All other adaptation options were rated as 'urgent' for case study 2, because, if implemented, they can save lives. 'Level of regret' was calculated for the three scenarios that could have been used to calculate the dimensions of each adaptation option. Based on these, the applicability value of each adaptation option was calculated six times, because there are two case studies and three scenarios.

5.2 Results

Results obtained using the previously described data and equation are synthetised on Table 5 and represented in Figure 2, where it is easy to observe three clusters. The first is marked with a red oval. It comprises adaptation options that, no matter which case study, have an 'applicability level' up to one. That is, these are options that should be implemented straight away, because they have low economic implementation costs and significant impacts. These include education and public awareness, community participation, planning and legislation, hazard reduction burns in fire-prone natural areas, shutters and sprinkler systems, protection of natural systems and reafforestation close to waterways and warning systems. The second cluster, which is inside the blue oval, includes construction of seawalls and multistorey building with the lower level planed as non-living areas. Their particularity is that their applicability values significantly varied accordingly to the case study. For case study 1, where there are no immediate life and death threats, they rated in average 3 and 8, respectively. That is, within the lower half of the spectrum. These results indicate that, while there is no urgency, such options should be further investigated and discussed, because, while expensive, they have the potential of producing relevant outcomes in the future. These are options that maybe should be implemented in the future. For case study 2, these adaptation options rated on average 0.2 and 0.4, because they can immediately save lives, hence there is a sense of urgency on their implementation. Cluster 3 includes only one adaptation option, limiting life of houses to minimise financial outlay, which was rated between 12 and 18, depending on the case study and scenario used for planning.   That is, among all the options tested; this is the least applicable adaptation option.

Table 5. Applicability level of adaptation options

Adaptation options	Average	CASE 1			CASE 2		
		1.5°C	3°C	5°C	1.5°C	3°C	5°C
1. Planning and legislation	0.1	0.1	0.1	0.1	0.0	0.0	0.0
2. Hazard reduction burns in fire-prone natural areas	0.1	0.3	0.3	0.3	0.0	0.0	0.0
3. Shutters and sprinkler systems	0.1	0.3	0.3	0.3	0.0	0.0	0.0
4. Protection of natural systems and reafforestation close to waterways	0.2	0.4	0.4	0.4	0.0	0.0	0.0
5. Education and Public awareness	0.3	0.5	0.5	0.5	0.1	0.1	0.1
6. Community participation	0.5	0.5	0.5	0.5	0.5	0.5	0.5
7. Warning systems	0.6	1.0	1.0	1.0	0.1	0.1	0.1
8. Construction of seawalls	1.6	3.6	3.6	1.8	0.2	0.2	0.1
9. Multistorey building with the lower level planed as non-living areas	4.2	9.0	9.0	6.0	0.5	0.5	0.3
10. Limiting life of houses to minimise financial outlay	16.0	18.0	18.0	12.0	18.0	18.0	12.0

Figure 2. Applicability level of 10 adaptation options
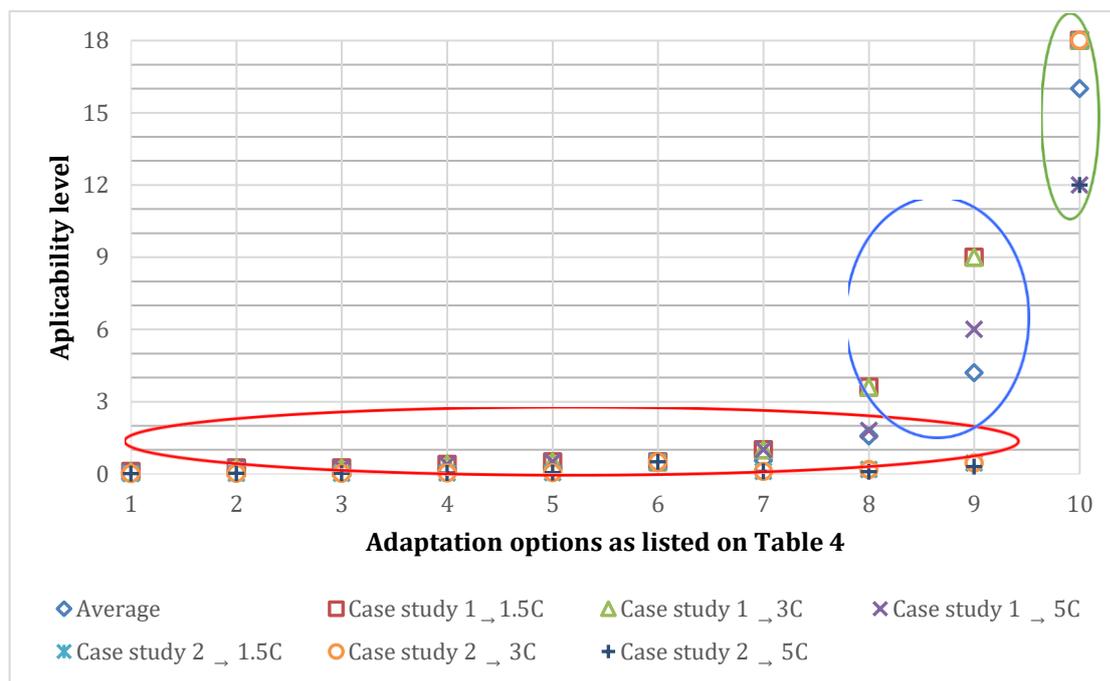
Number on X-axis indicates adaptation options with numbers following the same order as presented on Table 4. Cluster 1 is market with a red oval, cluster 2 with a blue oval and cluster 3 with a green oval.

6. Discussion

6.1. What do the numbers mean?

Results obtained from using the proposed equation, indicators, values and case studies are in accordance with what one could have expected. Results, however, indicate a level of precision that adds unnecessary complexity to the task of ranking options. Unnecessary, because in most cases a single adaptation option will not solve the challenges. Instead, it is likely that a group of options

needs to be implemented together.   Hence, it makes little difference whether an option rates 0.1 or 0.2.   This difficulty can be solved with a scale that determines what needs to be implemented on the short, medium and long term, and what should not be implemented at all.   From the results obtained, we can learn that options that are inexpensive and have immediate significant positive impacts, as well as those that can save lives, have an applicability level up to one.   Those that are expensive, but are expected to have significant positive impacts in the future, rated from 1 to 4.   Those that are expensive and are believed to have limited positive impacts in the future rated between 4 and 10.   Above ten are those options that are perceived as having low cost-benefit, hence should not be applied, unless the circumstances change. Based on this, the scale presented on Table 6 is proposed to help on understanding the results obtained.

Table 6. Scale for analysing the applicability level

Applicability level	When to implement the option
Up to 1	Short term
1.1 to 4	Medium term
4.1 to 10	Long term
More than 10	Only to be implemented if circumstances change

6.2. Who pays the bill?

Prioritizing adaptation options is usually necessary due to limited funds. Yet, costs of adaptation are not to be solemnly paid by one stakeholder, instead are likely to be shared by local councils (e.g. construction of seawalls), local residents (e.g. construction of multistorey building with the lower level planed as non-living areas and limiting life of houses to minimise financial outlay) and NGOs (e.g. education and public awareness). To capture this variety of economic sources, a new indicator needs to be introduced, e.g. 'stakeholder responsible for implementation of adaptation option'. This will allow separating and ranking options accordingly to the paying source.

7.0. Conclusion

This work focused on developing a simple process for assessing the applicability level of climate change adaptation options.   To do so, it built on previous research that had similar objectives, yet used complex techniques, which require sophisticated knowledge. Hence, are not practical to be used by community members.   From these researches, essential criteria to assess the applicability level of adaptation options were identified. These were reworded as indicators, and possible states were specified. The relationships between indicators were defined on an initial equation. Two case studies, one real and one fictional, and ten adaptation options were used to test the equation. Analysis of the results obtained indicates that, while the outcomes are within expected, an extra indicator would help on separating paying sources, and a scale of 'applicability levels' would help on assessing the order in which options should be applied.

At the end, nine indicators were deemed as essential for assessing the applicability level of adaptation options. These are: timing, costs, co-benefits, cascading effect, reversibility, negative impacts, flexibility, scenario and paying source.   The scale proposed incorporates four gradations depending on the time frame for implementing the options: short term (when applicability level is up to 1), medium term (from 1.1 to 4), long term (from 4.1 to 10), and not to be implemented unless circumstances change (10.1 and above).

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