2023

The International Mathematical Modeling Challenge (IM^2C)

Summary Sheet

It lies in the nature of humankind to always strive for the best possible outcome. In the case of land usage, it was quite evident in the last century what “best” meant. It meant trying to generate as much wealth as possible through a given plot of land. By today's standards however, it is not enough to only regard the economical aspect of land usage. In a society that is becoming increasingly social and climate aware, it is more important than ever to consider the ecological and social consequences when developing a parcel of land. Nonetheless, it is still in the interest of every landowner to profit as much as possible through their property. So how can every landowner utilize their piece of land in a way that benefits society and does no harm to nature, all whilst generating a maximum amount of profit? What does the “best” usage of land depend on and is “best” quantifiable? In this paper we aim to find a general definition for the “best” usage of land, in the hopes of assisting the community leaders and business planners of our given parcel of land in their endeavor to develop it.

In order to quantify “best”, we chose 12 different parameters, on which our calculations would later on be based. Said parameters can be subdivided into the categories physical, social, ecological and economical. We then took the parameters to calculate a potential development’s desirability to be built and suitability to be built on a plot of land depending on the land’s physical properties.

Our model evenly divides a given parcel of land into smaller chunks to precisely evaluate each chunk’s best usage. Therefore, the result is a very comprehensive description of how a parcel of land would be used ideally.

Additionally, our model possesses the ability of calculating the “best” land usage of a given parcel, while regarding a budget limit, as the best option picked out by the model might not be affordable for everyone. It is worthwhile noting the significant changes in our model’s solutions depending on the budget it is given. We further examine such changes in solution in our sensitivity analyses.

Although great, our model can still be improved. The implementation of more physical aspects such as the weather in the to be developed area can greatly improve the accuracy of our decision-making metric.

Letter to the decision makers

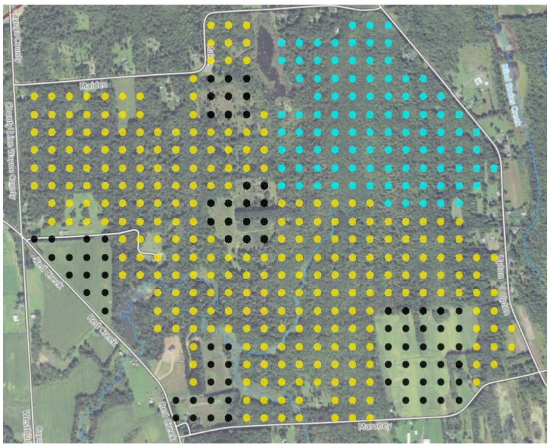
Dear community leaders and business planners of the intriguing parcel of land we have assessed,

It is of our great delight to have been able to deeply analyze your plot of land over the course of the last 5 days. In doing so, we were able to test our newly developed quantitative decision metric for the “best” usage and are delighted to say that we are very satisfied with our results.

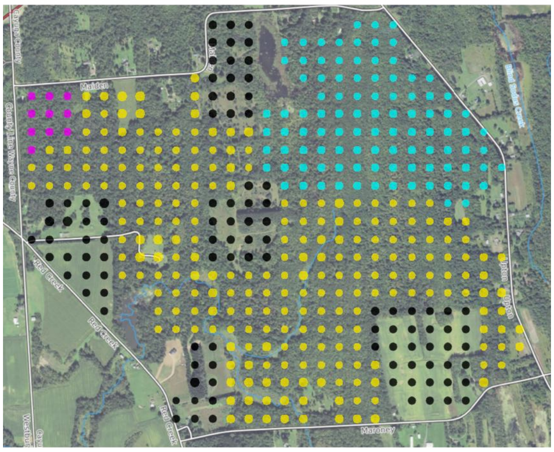
To determine the best usage of a piece of land, our model regards several different parameters. Examples of physical parameters we take into consideration are cell coverage, slope and aspect. In addition, as climate change affects all of us, our model also regards ecological parameters, e. g. tree density which correlates with deforestation. However, as we also have your financial interest in mind, our model puts a heavy emphasis on the profit and upfront costs of a potential development of your parcel of land.

With the help of a grid system we use, our model outputted a detailed description of the ideal usage of your parcel of land. It does not only calculate what the best development options for your plot of land would be, but how these should be distributed over your property in order to achieve the truly best solution.

As we could not be sure what budget you have at your disposal, our model can be given a certain budget to work with. The following two solutions our model calculated assume a budget of 100,000,000 $ and 200,000,000 $ respectively.



Result Overlay 1; Budget: 100,000,000$; Yellow: Farmland; Black: Agrivoltaics; Turquoise: Solar Array



Result Overlay 2; Budget: 200,000,000$; Yellow: Farmland; Black: Agrivoltaics; Turquoise: Solar Array; Pink: Outdoor Sports Center

We hope that our evaluation of your parcel of land can assist you in your final decision on how to utilize it. We are very grateful for your cooperation and wish you good luck in developing your estate.

Best regards,

The IMMC Team 2023030

Contents

1 Introduction

Overpopulation, rising sea levels and an increasing lack of resources and energy deficiency. All these are detrimental problems that our society is and will be facing in the foreseeable future. Therefore, it is of greater necessity than ever for humanity to be as efficient as possible with resource allocation and to always utilize land in the best way possible. But what exactly does it mean to utilize land in the “best” way? Is “best” quantifiable and if so, what metrics would have to be regarded and how would they influence the calculation of “best”?

In an effort to define “best” quantitatively, we have created a mathematical model and program on the basis of our given land parcel that calculates the most ideal use of a given land plot in regard to the land’s physical properties and various other metrics.

1.1 Problem restatement

1. Determine a quantitative decision metric that defines “best” so the decision makers can feel confident in their final use of the land. The metric should consider short- and long-term benefits and costs.

2. Choose at least two of the options listed above and determine the values of those options in your “best” metric. Explain and defend your values or use a range of values to better understand the effects and sensitivities of your assumptions.

3. Re-evaluate the options you identified in the previous question using your “best” metric, in a scenario, where a very large semiconductor fabrication facility (fab) is built in Clay, NY, USA, a town just north of Syracuse. The new plant will directly support 9,000 jobs and create nearly 40,000 additional jobs.

4. Discuss how appropriate your model would be for use in an environment you are familiar with. Consider how generalizable your model is to other locations.

2 Definitions and Assumptions

2.1 Definition of Important Terms in the Paper

2.1.1 Agrivoltaic Farming

Based on a guideline on Agricultural Photovoltaic by the Fraunhofer Institute[1], there are two main ways to gain electrical energy by placing photovoltaic modules above farmland. The first being the placement of solar panels >4 meters above the farmland, enabling the plantage of common grain types. The capital expense per kilowatt of installed power for this measure is 1,300$.

The second option is to build structures to suspend the photovoltaic modules only 2.5 meters above the ground. Beneath the solar array, the most typically grown plants are of horticultural nature. Lowering the solar panels also lowers the capital expenses per kilowatt of installed power to 940$, for the substructure for supporting the photovoltaic modules does not have to be as strong.

Given the lower price of building the second agrivoltaic solution together with the typically higher profit of cultivating vegetables and different types of cabbage[2], we decided to only consider the second option for our model, acknowledging the potential changes in agricultural infrastructure that may be necessary.

2.1.2 Aspect

Aspect is the description of the compass direction a topographic slope faces.

[1] See References [1]
[2] See References [2]

2.2 Definition of Variables

Table 1; Definition of Variables

S_{So}	Suitability value Solar Array
S_{Fa}	Suitability value Farmland
S_{Af}	Suitability value Agrivoltaics
S_{Sp}	Suitability value Sports Complex
S_x	Suitability value for development option x
D_{So}	Desirability value Solar Array
D_{Fa}	Desirability value Farmland
D_{Af}	Desirability value Agrivoltaics
D_{Sp}	Desirability value Sport Complex
D_x	Desirability value of development option x
B_{So}	Social, ecologic and economic benefit of Solar Array
B_{Fa}	Social, ecologic and economic benefit of Farmland
B_{Af}	Social, ecologic and economic benefit of Agrivoltaics
B_{Sp}	Social, ecologic and economic benefit of Sports Complex

2.3 General Assumptions and Justifications

In the description of our task, it is stated that the climate as well as the soil are to be considered ideal for farming as well as solar power generation.

The terrain of the parcel of land is very flat averaging at 2° of slope. This is why we considered it as completely flat and ideal to build on.

In order to consider any economic aspects, we had to, after a lot of research, make some assumptions about how costly the different land development options are.

Table 2; Comparison of different costs

	Cost to build	Cost for pot. deforestation	Annual Profit
Solar Array[3]	194,000$	30,625 $ - 122,500$	30,000$
Regenerative Farm[4]	7,900$	30,625 $ - 122,500$	1,400$
Agrivoltaic Farm[5]	320,000$	30,625 $ - 122,500$	40,000$
Sports Complex[6]	607,000$	30,625 $ - 122,500$	-50,000$

4 Exact description of different parameters

In our approach to quantitatively define "best", we had to decide which parameters would be relevant in our calculations. We quickly concluded that the different parameters can be grouped into several categories and sub-categories. While deciding on how to use a plot of land to its fullest potential, one must regard the physical properties of the plot of land in addition to the economic and social aspect of a potential new development. It is important to understand that we will use the physical parameters in order to evaluate whether a plot of land is suitable for a certain development type, whereas the economic and social parameters will be used to assess whether it is actually worth developing the plot in a certain way. The parameters we chose are based on the relevancy we see in them after extensive research, one scientific paper[7], and the limited amount of knowledge we have on the physical properties of the given parcel of land. As for the economical parameters, the quantification of profit and upfront cost was straight forward. For other parameters, such as the social parameters or "tree density", we had to define how we would quantify them. All exact definitions for the quantification of each parameter are listed below.

Our parameters are tuned to 4 of the suggested land development options: **Agrivoltaic farm, solar array, regenerative farm, and outdoor sports complex**.

[3] See References [3]
[4] See References [4, 5]
[5] See References [1, 2, 3]
[6] See References [7]
[7] See References [1]

However, since our parameters are very general, yet easy to specify for a given plot of land, they are easily applicable onto other development ideas.

It is helpful to note that in our model we have subdivided the parcel of land into 451 squares with an area of 4900 m^2 respectively, for this allows us to examine the given plot of land in a more sophisticated way. This grid system is further elaborated on in chapter 5.

4.1 Physical Properties

Tree density (Td)

Trees that are located on a given chunk of land must be expensively removed to allow for further development of said plot.

To determine each chunk's tree density, we looked at satellite images and gave every chunk a value of either 0, 0.25, 0.5, 0.75 or 1, where 0 means that no tree coverage is visible on a chunk and 1 means that an abundance of trees is to be seen.

Distance to street (dS)

When regarding what is going to be built on a chunk of land, a smaller distance to roads might be advantageous, e. g. when building a sports complex, it helps to be nearer to a road, so that visitors can access the facility easily. For other development ideas, such as a solar array, the distance to roads does not matter as much, as there is no real need for having a road in the near vicinity.

Depending on a chunk's distance to the nearest street, its variable was assigned a value between 0 and 1 (0.1 increments). Chunks the nearest to a street have the value 1. The further away the chunk is from a street, the smaller the value is that it is assigned to.

Cell coverage (C)

When building a sports complex or agritourist site, it is desirable to have cell coverage at said location for people using social media and basic communication.

The values 1 and 0 are assigned to the variable, where 1 means that there is cell coverage and 0 means that there is no cell coverage.

Slope (s)

The steeper a chunk of land, the harder it is to develop. However, it is still far easier to build solar plants on a steep chunk than it is to build a sports complex, which is why we also regard slope in our calculations.

Depending on a chunk's average slope, the variable is assigned the chunk's slope value in degrees. A slope with an angle of 45° would therefore receive the value 45.

Aspect (A)

For photovoltaic and agriculture, it is of convenience to be located on a chunk of land with a south-facing aspect. This is because south-facing bits of land experience more solar radiation than other bits of land[8].

The variables of chunks with primarily southern aspect received the value 2, the ones with eastern or western aspects received the value 1 and of chunks with northern aspect were valued 0.

Surrounding population (sp)

For a sports center to be built, it is necessary to look at whether there is demand for a sports center. The easiest way to approximate said demand is to regard the size of the surrounding population. Therefore, we look at the population size in a 50 km radius around our land parcel[9].

The variables of all chunks are given the same value, as their surrounding populations are practically the same.

Bodies of water

Bodies of water might prohibit further development of a chunk of land. Here it is important to differentiate between a river flowing through a plot, only causing partial limitations and lakes or smaller ponds taking up the whole area of said chunk as they take extensive measures to be made useful for any of our desired measures.

If there is a river on a chunk, the variable for the land receives the value 0.5, if there is a lake or pond on the plot, it receives 0. Else, it receives 1.

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[8] See References [8]
[9] See References [10]

Farmland (F)

Space that is currently used for farming most desirably stays in use for farming, due to the nonexistent effort and cost of changing any terrain or converting land. Another fine option is to convert the land to agrivoltaic use, as the farmland stays in use for farming with only the cost of placing photovoltaic modules on top being an issue.

If the chunk consists of mostly farmland, the farmland variable for the chunk is given a value of 1. Else, it receives the value 0.

4.2 Economic Properties

Expected annual profit

We regard the annual profits that different developments would make. The greater the profit a development makes, the higher the desirability to utilize a chunk of land for said development.

Quantification is trivial.

Upfront cost of development

When regarding the annual profit of a certain development type, the long-term aspect of the investment is the annual profit. In contrast, the upfront cost of developing the chunk of land is the short-term aspect of the investment.

Quantification is trivial.

4.3 Social Properties

Expected benefits to society after development

It is the role of community leaders to supply their community with recreational and leisure activity. Therefore, if a certain development type carries social benefits, that should positively affect the desirability of said development. In addition, many developments bring along a considerable amount of wealth to surrounding businesses, due to the influx of visitors the area witnesses. A prominent example would be the development of outdoor sports complexes.[10]

[10] See References [7]

If a chunk is developed to a sports complex (more accurately a fraction of a sports complex), the development is valued at $\frac{sp}{100{,}000}$. When building a solar array or agrivoltaic farm, the development is rated 0.5. Otherwise, a rating of 0 is given.

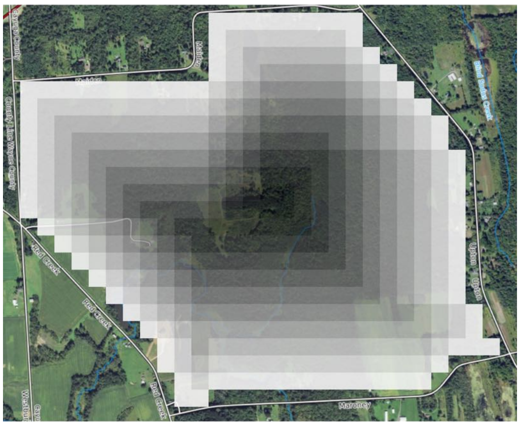
Expected political backlash after development

Deforestation and the destruction of habitats all cause substantial political backlash.

For every development that requires deforestation, a political backlash is to be expected. However, since all development options given to us require deforestation, we disregard this aspect in our calculations.

5 Grid system

The land parcel that is given to us is 3 km^2 large. In our approach we have decided to subdivide this parcel of land into 750 square pieces of land[11] with an area of 4900 m^2 each. We did so, to evaluate the "best" usage of each square piece of land. The result is a very detailed description of how the whole land parcel should be used. Our model does not only assess what should be built on the parcel of land, but where everything should be built. For each chunk of land, we have examined its physical properties and given it a value for each physical parameter. To illustrate these values, we have created color maps for all physical parameters. The following maps represent "distance to street" and a general view of the grid. The other maps can be found in the appendix. As for the economic and ecological parameters, it makes no sense to create maps for these. That is, because they are not dependent on the physical properties of a chunk of land, but on the consequences of developing it.



Grid Showcase 1; New York, Distance to Street Color Map overlayed on satellite image

Grid Showcase 2; New York, Grid overlayed on satellite image

[11] Also called chunks

6 Metric for "best"

As previously stated, we have subdivided our land parcel into 750 smaller chunks. Each chunk has its parameters, with which we could then assess two different aspects. Firstly, by regarding the physical parameters of a chunk, we could evaluate how suitable said chunk is for different developments. Secondly, by viewing the economic and social benefits a certain development would entail, we were able to define a second metric to determine the desirability of utilizing a plot of land for a certain development. In our model, a higher score for both metrics is always desirable. Our final quantitative decision metric that defines the "best" utilization of a plot of land therefore takes both aspects into consideration, in an effort to combine both aspects into one metric.

6.1 Metric for land suitability

For each chunk of land, we calculated its suitability for a solar array, agrivoltaic farm, regenerative farm, and outdoor sports complex. The calculation of said suitabilities differ slightly, because for each development different parameters play a bigger or lesser role.

Solar Array

$$S_{So} = \begin{cases} \frac{s}{200} - 4Td, & A = 2 \\ -\frac{s}{450} - 4Td, & A = 1 \\ -\frac{s}{200} - 4Td, & A = 0 \end{cases}$$

For solar panels, it is of advantage to be facing southwards, as they can then produce the most amount of energy. If they are on a slope with a southern aspect, they can produce more energy, the steeper the slope is[12]. The opposite is true for a slope with a northern aspect. Therefore, when $A = 2$, S_{So} is increased by $\frac{s}{200}$. We have found a factor of $\frac{1}{200}$ to best put the slope parameter in relation to other parameters. When $A = 0$, $\frac{s}{200}$ is subtracted from S_{So}, as a northern aspect acts exactly opposite compared to a southern aspect. For $A = 1$, an increased slope is disadvantageous, although not as disadvantageous as for $A = 0$, thus we have multiplied slope with $\frac{1}{450}$.

[12] See References [8]

In order for any solar arrays to be built, no trees can be left on a chunk of land. Therefore, a certain amount of deforestation must happen, for solar arrays to be built. When the tree density on a chunk is high, more trees must be chopped, which we regard as negative, for one due to the costs but also because of the ecological consequences of deforestation. For that reason, we always subtract $4Td$ from S_{So}.

Regenarative Farm

$$S_{Fa} = \begin{cases} -4Td \ + 5F + dS + \dfrac{s}{400}, & A = 2 \\ -4Td \ + 5F + dS - \dfrac{s}{900}, & A = 1 \\ -4Td \ + 5F + dS - \dfrac{s}{400}, & A = 0 \end{cases}$$

For the creation of farmland, tree coverage is as disadvantageous as it is for solar panels. Thus, we also subtract $4Td$ from S_{Fa}.
As 30% of our given land parcel is farmland already, developing a chunk of farmland to a regenerative farm does not require much effort. Therefore, we add $5F$ to S_{Fa}.
Another factor to take into consideration is each chunk's distance to the nearest road, as it is far more convenient for the farmer to have direct road access. Therefore, we also add dS to S_{Fa}.
When considering farming on a plot of land, the aspect and slope of the land are not as important as they are for solar farms. This is why said aspects are weighted less than for solar arrays.

Agrivoltaic Farm

$$S_{Af} = \begin{cases} \dfrac{s}{250} - \ 4Td \ + dS \ + \ 3F, & A = 2 \\ -\dfrac{s}{550} \ - 4Td \ + \ dS \ + 3F, & A = 1 \\ -\dfrac{s}{250} - \ 4Td \ + \ dS \ + \ 3F, & A = 0 \end{cases}$$

To evaluate a plot of land's suitability for an agrivoltaic form, we look at the same parameters we use for solar arrays and regenerative farms. However, we weigh slope and F less, as agrivoltaic farms are not affected by slope and F as much as solar arrays are.

Outdoor Sports Complex

$$S_{Sp} \ = \ -4Td \ + 5dS - \frac{s}{10} - 2F + C$$

Like all the development ideas listed above, the tree coverage creates unpleasantries for building a sports complex and thus the same amount of tree density is subtracted from S_{Sp}.

The distance to the nearest road also matters a lot when planning a sports complex, since people generally prefer shorter and easier routes to their destination. Hence, we add $5dS$. People also enjoy sharing their achievements on social media or listening to streamed music from the internet while performing exercise. This is why we added C. For a sports complex, it is of great necessity for it to be built on an even surface, e.g., no football court can be built on a slope. Natural slopes must be compensated for by terraforming, resulting in great cost. Thus, we heavily penalize the slope factor. Because the creation of this leisure facility causes the sealing up of ground that could otherwise be used ecologically friendly, we deduct $2F$.

6.2 Metric for long-term development desirability

In addition to calculating the suitability of developing a chunk of land in a specific way, it is necessary to regard the economic and social benefits that would follow after developing the piece of land. Therefore, we have formulated several methods to calculate the economic and social benefits of our 4 different development options. In doing so, we had to decide how to weigh the short-term loss of developing a chunk, compared to the long-term benefits, e.g. the initial cost of construction vs. the expected annual profit that results from the development. In our sensitivity analyses we have found out that a short-term-long-term coefficient of $C_{sl} = \frac{annual\ profit \cdot 10}{upfront\ cost}$ suits our model the best.

Solar Array

$$D_{So} = \frac{30{,}000 \cdot 10}{194{,}000} + B_S$$

Regenerative Farm

The production of food is and will always be a vital part of a functioning society. Farming is not very lucrative, though, as the food prices are being kept low so that the public can afford and enjoy healthy and nutritious food.

$$D_{Fa} = \frac{1{,}400 \cdot 10}{7{,}900} + B_{Fa}$$

Agrivoltaic farm

$$D_{Af} = \frac{49{,}000 \cdot 10}{320{,}000} + B_{Af}$$

Outdoor sports complex

$$D_{Sp} = \frac{-50{,}000 \cdot 10}{1{,}214{,}000} + B_{Sp}$$

6.3 Quantitative decision metric that defines “best”

To obtain a quantitative decision metric that defines “best”, we then combined our metrics for suitability and desirability into one equation. Our decision metric gives each development option a rating. The development option with the highest rating is therefore the “best use” of a given chunk of land.

$$FinalRating = D_x + S_X$$

6.4 Implementation of limitations

In order to make our model more realistic, we have formulated further limitations that have to be taken into consideration when using our model. These limitations were implemented in our Python program that calculates the best land use option for a whole given parcel of land. A more detailed description of the program is given in chapter 6.5.

Financial Limitations

Our model outputs the best usage of a given piece of land, also considering the price of that solution. However, one might not have an unlimited budget and the most ideal solution might not be affordable for every landowner. This is why we have implemented a system to limit the maximum amount of money the model is allowed to spend[13].

Size Limitations

Our given parcel of land is 3 km^2 large. In a scenario where our decision metric would suggest developing the whole area into one solar array, that still would not be a feasible solution, as only the biggest solar farms are 3 km^2 in size. We therefore limited the maximum size of a solar farm to 0.49 km^2, a number slightly larger than the average solar farm in New York State[14]. Same limitation applies to the creation of agrivoltaic farms. In case one desires to change the size limitations to better fit one’s specific needs on another plot of land, this is very easily done.
As for outdoor sports complexes, we limited the maximum number of chunks used to $\frac{sp}{50{,}000}$. We have chosen this value in an effort to replicate the relation between the size of real outdoor sports complexes and their surrounding population[15].

[13] See Appendix [Graphs]
[14] See References [6]
[15] See References [7]

Since regenerative farms are generally not tightly restricted in size, we have not limited their size in our model.

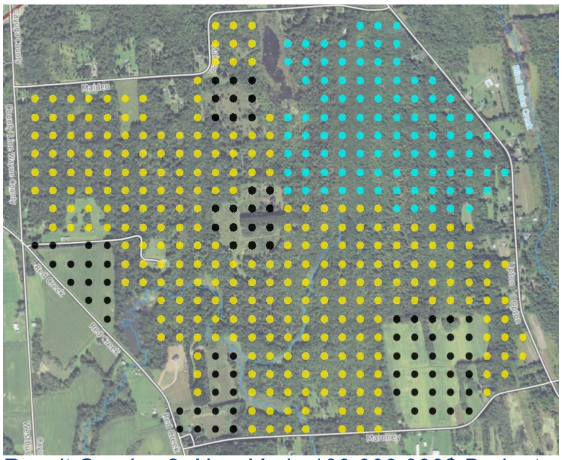
Terraforming Limitations

We have decided not to develop any chunks of land that are part of ponds, as doing so would disrupt ecosystems [**source**] and would be expensive too.
If a small stream of water flows through a chunk of land, we prohibit developing the chunk to a sports complex, as the water flow would have to be disrupted. However, we still allow solar arrays, regenerative farms and agrivoltaic farms to be built there, as those can be constructed around the stream of water.
In addition, we have decided to prohibit the further development of already developed land, as that may lead to legal problems.

Limitations in scattering

When calculating the best usage of a parcel of land, our model still had one considerable disadvantage. No parameter ensured that all chunks of one development type were neighboring chunks. The consequence was that our model would often give highly unrealistic solutions. We therefore implemented that all chunks of one development type must be neighboring chunks.

Result Overlay 1; New York, 100,000,000$ Budget, No Scatter Prevention



Result Overlay 2; New York, 100,000,000$ Budget, With Scatter Prevention

6.5 Program

With our quantitative decision metric, we were capable of calculating the best development option for each chunk of land on our land parcel. However, calculating the best use of each chunk does not necessarily equate to the overall best use of the parcel of land, as we have discussed in the previous chapter. Therefore, it is our program's task to calculate each chunk of land's best usage in addition to complying with all limitations that we have set previously.

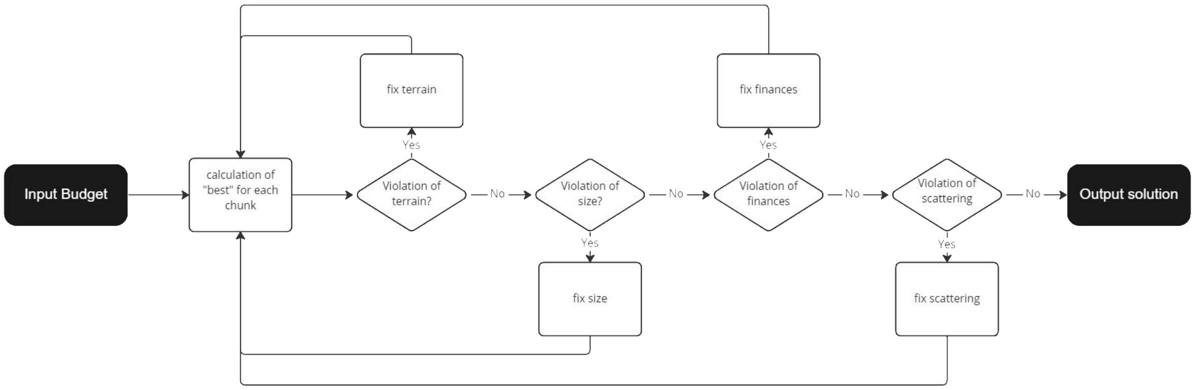


Figure 1; Structure of our program

As input, our program is given a budget to work with, in addition to all parameters for each chunk on our parcel of land. The program then calculates the best usage of each chunk and checks whether all limitations were met. If so, the solution can be outputted. Otherwise, the program adjusts certain evaluations, until all limitations are met.

fix terrain

When our program detects that a chunk, which should not have been developed, was nonetheless utilized, the development is undone.

fix size

If too many chunks are developed to one type, the chunks that scored the least in our metric for "best" are removed, until the limitation is not violated anymore.

fix finances

When the given budget is exceeded, the chunk that was most expensive to develop is given a debuff of -1 to its desirability score. This process is repeated, until the budget is not exceeded anymore.

fix scattering

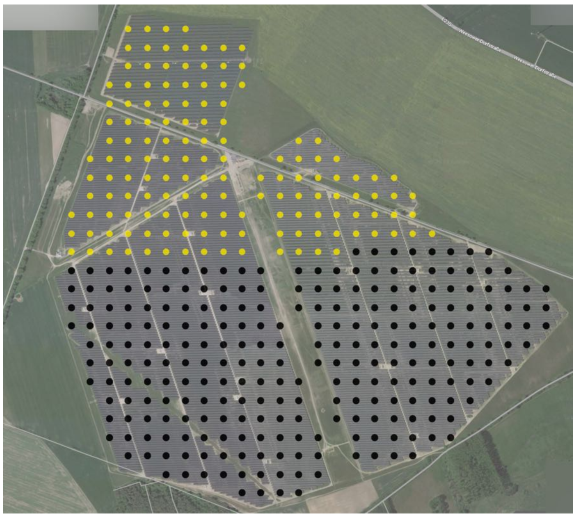
If a chunk's surrounding is not developed in the same way the chunk itself is, its suitability is lowered by 2.

6.6 Application of metric on real examples

To validate the accuracy of our metric and therefore our entire model, we applied it on real-life land development projects. The goal was to see whether our model's output matched existing modern projects, conducted by professionals.

6.6.1 Solarpark Weesow-Willmersdorf

The first example we examined our model with was the Solarpark Weesow-Willmersdorf, a 1.96 km² large area covered in solar panels, located roughly 25 km north-east of Berlin, Germany. The project, which turned farmland into a solar array, was completed in Q1/2022 and cost around 100 million Euros[16].
To test our model, we first gathered the necessary data to create the color maps[17] that feed our model with information[18]. Due to the very flat terrain and the simplicity of the parcel, this was a very straightforward process. We did not regard cellular coverage in this example, as the German cell service system is rather complicated, making it very difficult to access reliable data.
We then ran the model with the implemented cost restriction and cross-referenced our result with the actual project's outcome.



Result Overlay 3; Solarpark Weesow-Willmersdorf; 100,000,000$ Budget; Yellow: Farmland; Black: Agrivoltaics

Satellite Image 1; Solarpark Weesow-Willmersdorf ©Google

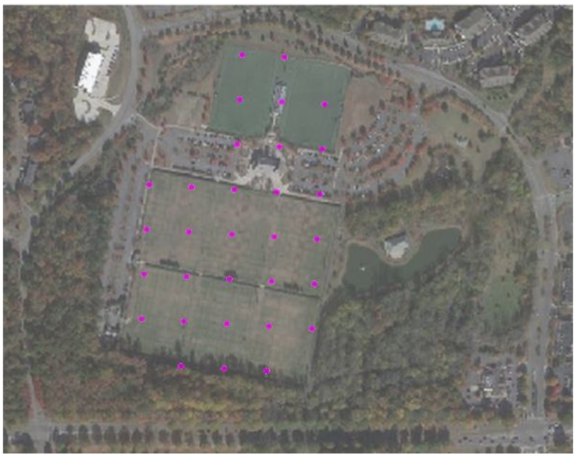
In the above maps one can see that the model's calculated best usage of the land differs to the actual usage of the parcel. This is explained by the different approaches the developers of the land and we took. Whilst the developers of the land, associates of the energy company EnBW (Energy Baden-Württemberg), aimed to maximize solar energy production[19], our model satisfied every parameter economically, ecologically,

[16] See References [11]
[17] See Chapter 5
[18] See Appendix [Color Maps]
[19] See References [11]

and socially. This is why our model, simply put, only “upgraded” existing farmland by placing agrivoltaic units in their place. The reason why not the entire area is covered in agrivoltaics, is that the model stayed within the budget of 100 million Euros, as the developers did as well. This is the same reason as to why the model did not decide to place an outdoor sports facility inside the parcel, even though the cosmopolitan city of Berlin is in the vicinity of the area.

6.6.2 Manchester Meadows - Rock Hill South Carolina

The Manchester Meadows sports complex is located about 30 km south of Charlotte, North Carolina and consists of 6 natural grass fields and two artificial turf fields, each of which is lighted[20]. Before the sports facility there was some mild tree coverage in the area that had to be considered when testing this parcel out in our model. Being located close to Charlotte, the surrounding population was to be considered and estimated to 1.75 million people. The outcome is shown below:



Result Overlay 4; Manchester Meadows – Rock Hill South Carolina; 14,000,000$ Budget; Pink: Outdoor Sports Complex

Satellite Image 2; Manchester Meadows – Rock Hill South Carolina ©Google

As one can see, the optimal land development chosen by the model matches the actual land development. This is due to the relatively small area, a high budget of 14 million $ and the direct proximity to a large city.

[20] See References [7, 9]

7 Proposed utilization of the parcel of land

With our metrics and program at disposal, we were then capable of computing the best utilization of our parcel of land. Through our sensitivity analyses we have concluded that the most prominent factor influencing the "best" land use is the budget at one's disposal.

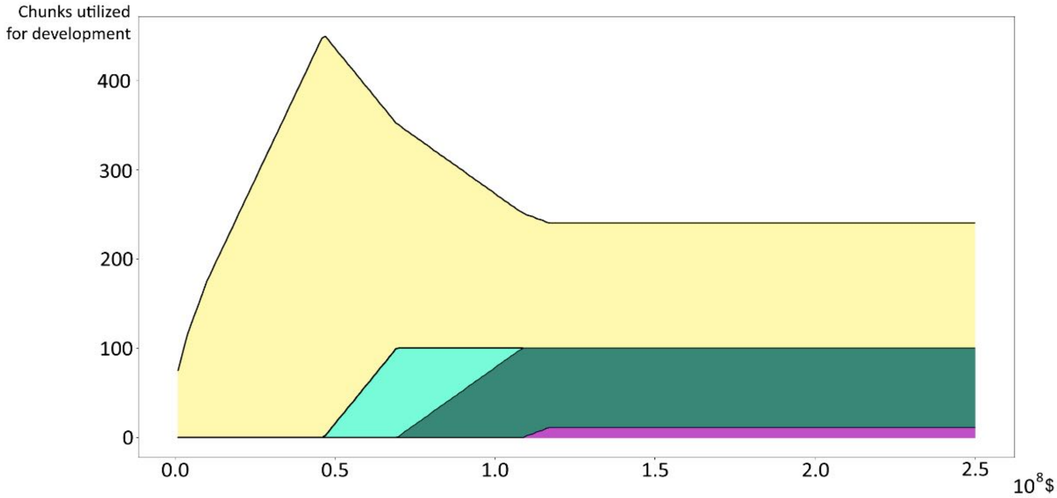


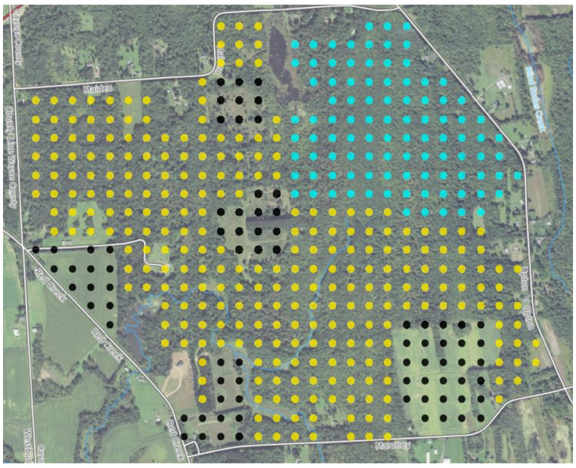
Figure 2; Number of Chunks utilized for land development for different options of development in relation to the capital expenses; Yellow: Farmland; Turquoise: Solar Array; Black: Agrivoltaics; Pink: Outdoor Sports Center

As can be seen, depending on one's budget, the "best" land use can heavily vary. What can be observed is that regenerative farming is the best solution for lower budgets. Solar arrays are the second cheapest solution. Agrivoltaic farms only seem to make sense when one's budget is above 700,000$. The most expensive option, an outdoor sports complex, is only feasible with a budget of over 1,100,000$. In the chart below, a comprehensive overview of our suggested solutions can be found.

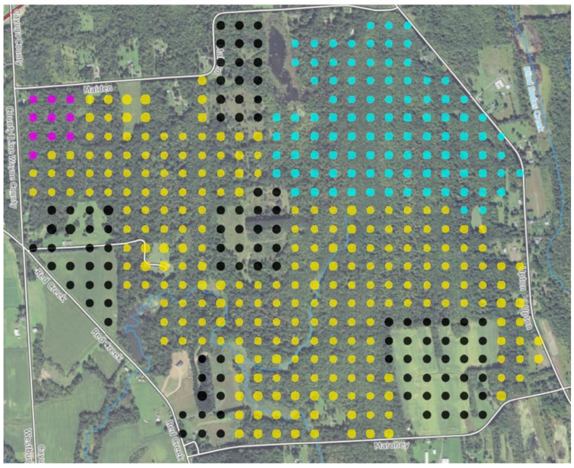
Table 3; Percentage of land use for different development options for different budgets

Budget (in $)	**Agrivoltaic Farm** (land use in %)	**Solar Farm** (land use in %)	**Regenerative Farm** (land use in %)	**Outdoor Sports Complex** (land use in %)
0	0	0	11	0
50,000,000	0	2	98	0
100,000,000	18	22.2	58.8	0
150,000,000	22.2	22.2	53.6	2
200,000,000	22.2	22.2	53.6	2
250,000,000	22.2	22.2	53.6	2

The graphics below show the exact distribution of development options for the budgets of 100,000,000 $ and >150,000,000 $.



Result Overlay 4; New York; 100,000,000$ Budget; Yellow: Farmland; Turquoise: Solar Array; Black: Agrivoltaics

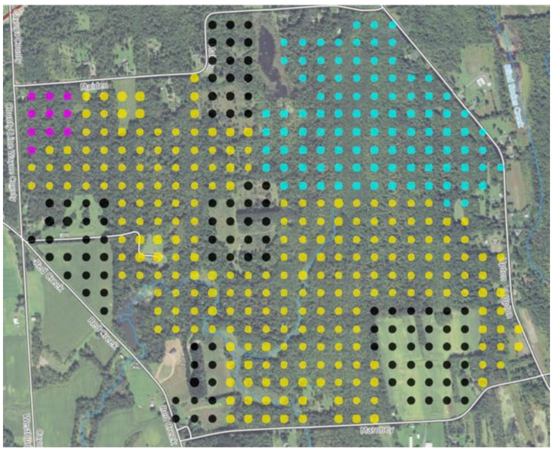


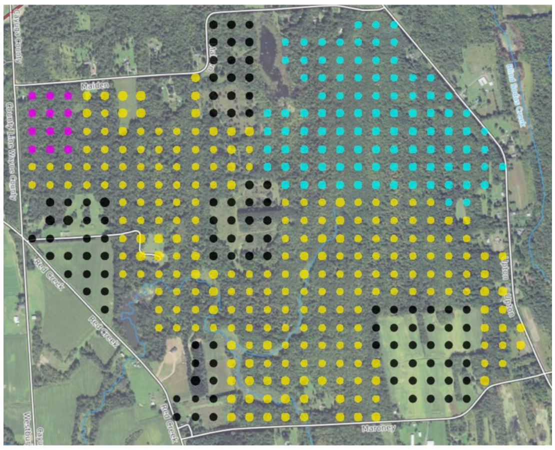
Result Overlay 5; New York; >150,000,000$ Budget; Yellow: Farmland; Turquoise: Solar Array; Black: Agrivoltaics

8 Changing Parameters

As stated in Requirement 3, we regard a scenario in which a large fab is built near our parcel of land. This results in a substantial population influx in the vicinity of the new employer. Increased need for infrastructure, leisure facilities and housing space is therefore inevitable. In order to estimate said influx in population, we assumed that every newly created job meant an increase of 3 in population, as the average household in the USA consists of 3 persons. We therefore calculated the influx in population to be roughly $Created\ Jobs \cdot Average\ Family\ Size = Population\ Influx$. Applying this formula to our scenario, we ended up with 147,000 new inhabitants in the vicinity of our parcel of land. The direct impact this has on our model lies in the change of value for the surrounding population[21], as this number is being increased by the amount of people that newly moved in. Running the model with the new values, we observed a 20% increase of area used for the outdoor sports facility, as the limitation to said area is directly bound to the size of the surrounding population.

[21] See Chapter 6.2





Result Overlay 6 & 7; New York; >150,000,000$ Budget;
Yellow: Farmland; Turquoise: Solar Array; Black: Agrivoltaics; Pink: Outdoor Sports Complex

9 Conclusion

To answer the question of how to make best use of a piece of land, we have developed a mathematical model that, incorporating physical, economical, ecological and social aspects, achieves just that.

The mentioned aspects include the terrain and relief of the land, the surrounding population, tree- and farmland coverage, as well as any potential bodies of water. In addition, the model takes the capital expenses of modifying the land and the resulting profit into account.

When assessing the 3 km^2 plot of land we had to analyze, many factors played in our favor, for the terrain was flat, the weather was to be assumed as ideal for farming and solar power generation and all necessary information was provided. Due to our model's nature, adapting it to different types of land is easy. Our grid system enables a detailed depiction of the area that is to be assigned a future purpose, no matter the complexity of said area, terrain and relief. The only change to the model that would have to be made is the incorporation of weather data for the desired territory, to accurately evaluate the efficiency of solar power and agriculture. In case the necessity arises of implementing more than the 4 development options we regard, it is easy to do so, as our parameters were chosen in a very general fashion. Hence, our model is very generalizable to other locations.

In conclusion, we believe we have found a way to determine the objectively best way to use land with the help of a quantitative metric.

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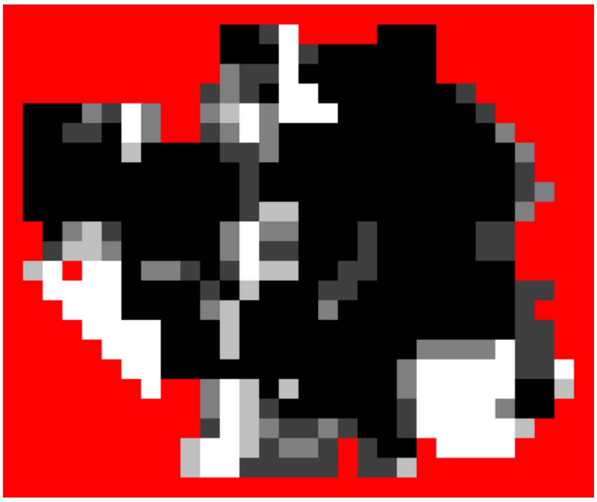
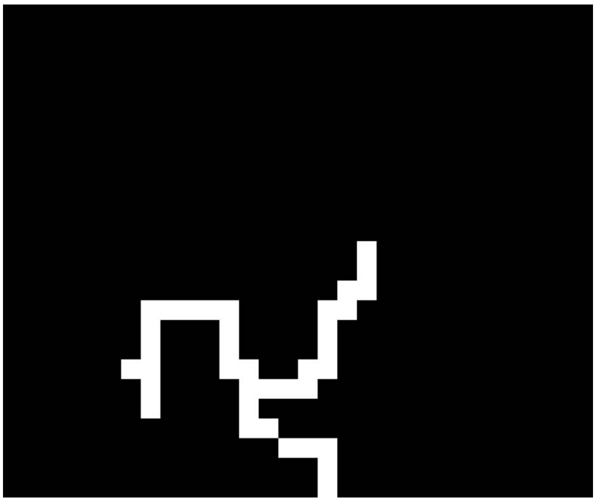
Appendix

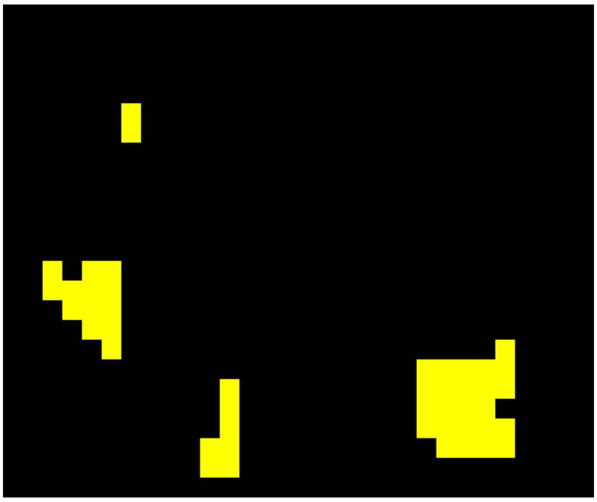
Color Maps



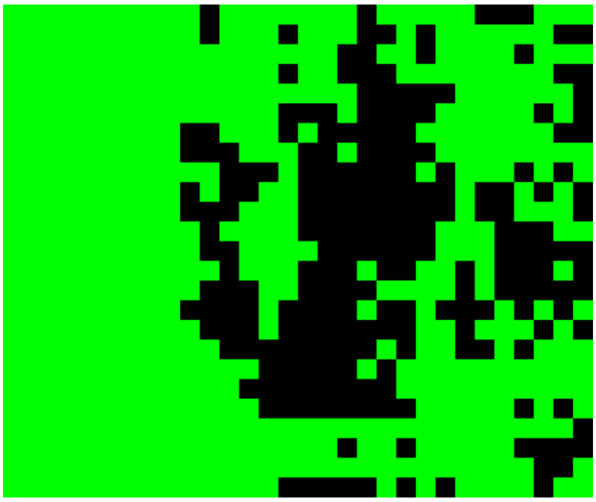
Color Map 1; New York Tree Coverage



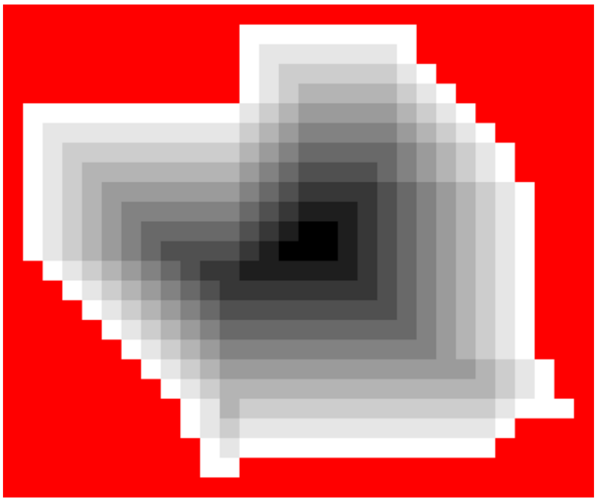
Color Map 2; New York River



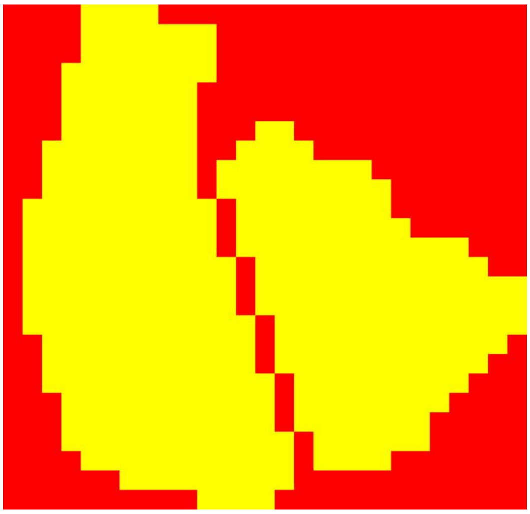
Color Map 3; New York Farmland



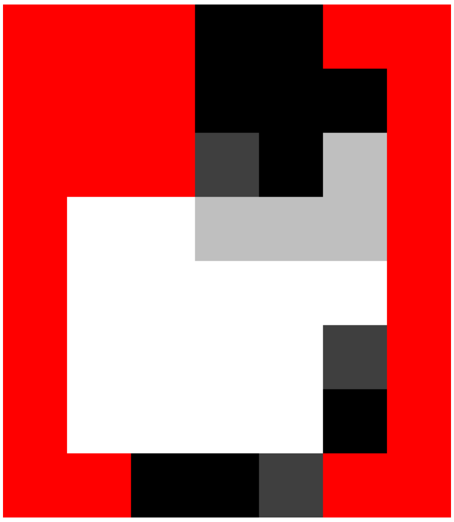
Color Map 4; New York Cell Coverage



Color Map 5; New York Distance To Road



Color Map 6; Solarpark Weesow-Willmersdorf



Color Map 7; Manchester Meadows Sports Facility, Tree Coverage

In every color map, one pixel represents one 70 meters by 70 meters large area. Farmland is represented by yellow, cell coverage by green and different stages of values described in chapter 4 by different shades of gray.

Graphs

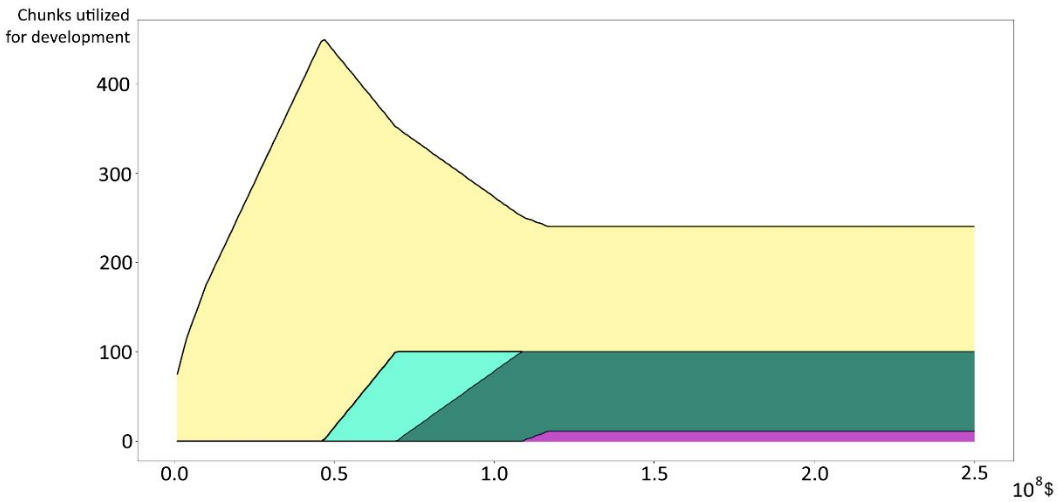


Figure 3; Number of Chunks utilized for land development for different options of development in relation to the capital expenses; Yellow: Farmland; Turquoise: Solar Array; Black: Agrivoltaics; Pink: Outdoor Sports Center