SOLAR ENERGY POTENTIAL ESTIMATION FOR WASHINGTON D.C.

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BACKGROUND

- As cities grow and energy demands rise, reliance on fossil fuels poses environmental and economic challenges. Transitioning to renewable sources like solar power is key to urban sustainability. Washington D.C. aims for 100% renewable energy by 2032(Here), leveraging its strong solar irradiance. However, the gap between current production and future needs remains significant. This project examines the city's solar energy potential, addressing challenges in adoption to support a sustainable transition and self-sufficiency.
- This state of the art paper has be an inspiration for the technique used in our analysis.

  This paper evaluates the accuracy and implications of using different Digital Surface Model (DSM) methodologies—photogrammetry from Google imagery and LiDAR data—for estimating solar potential on urban rooftops. Using the SEBE model within QGIS, the study highlights significant variations in solar potential results due to DSM discrepancies, especially in areas with complex topologies, where root mean square deviations (RSMD) range from 10% to 50%. However, simpler, flat rooftop areas showed less variability. The paper concludes with a suggestion to combine photogrammetry and LiDAR techniques to improve DSM accuracy for future solar cadaster applications. Ultimately it highlights the role of DSM precision in reliable solar energy planning.

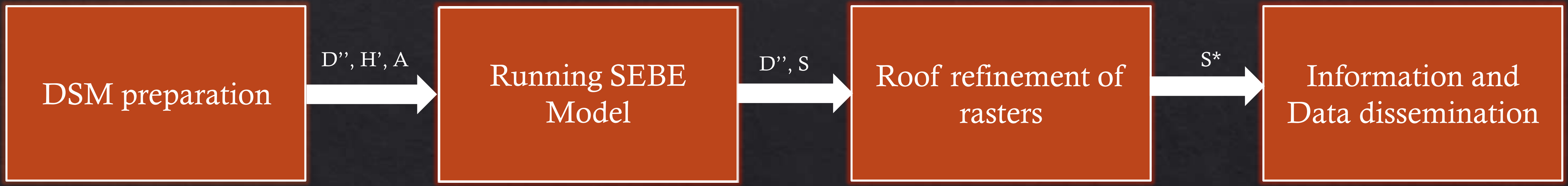
PROBLEM STATEMENT

- Washington D.C., with its abundant solar irradiance, has the potential to harness rooftop solar energy to meet a significant portion of its energy needs. However, **quantifying** the total energy generation potential from rooftops across the city remains a challenge, requiring accurate analysis of spatial data such as Digital Surface Models (DSM) and building footprints.
- Objective: To calculate the total solar energy generation potential (in GWh) for Washington D.C. by analyzing DSM (.tif) and building footprint (.shp) data, identifying suitable rooftops, and estimating energy output if all rooftops are utilized for solar energy harnessing.

DATASET

Data	Characteristics	Time stamp	Format
DSM data	Resolution: 1m, taken from LIDAR flown in single lift.	1st March, 2024	.tif
Building footprints	Contains polygons representing planimetric buildings.	Updated in September 2024	.shp
Solar irradiance data	All sky surface Direct normal shortwave irradiance + All sky surface Diffuse shortwave irradiance + All sky surface shortwave downward irradiance	1st January, 2022 – 29th February, 2024; hourly data.	.txt

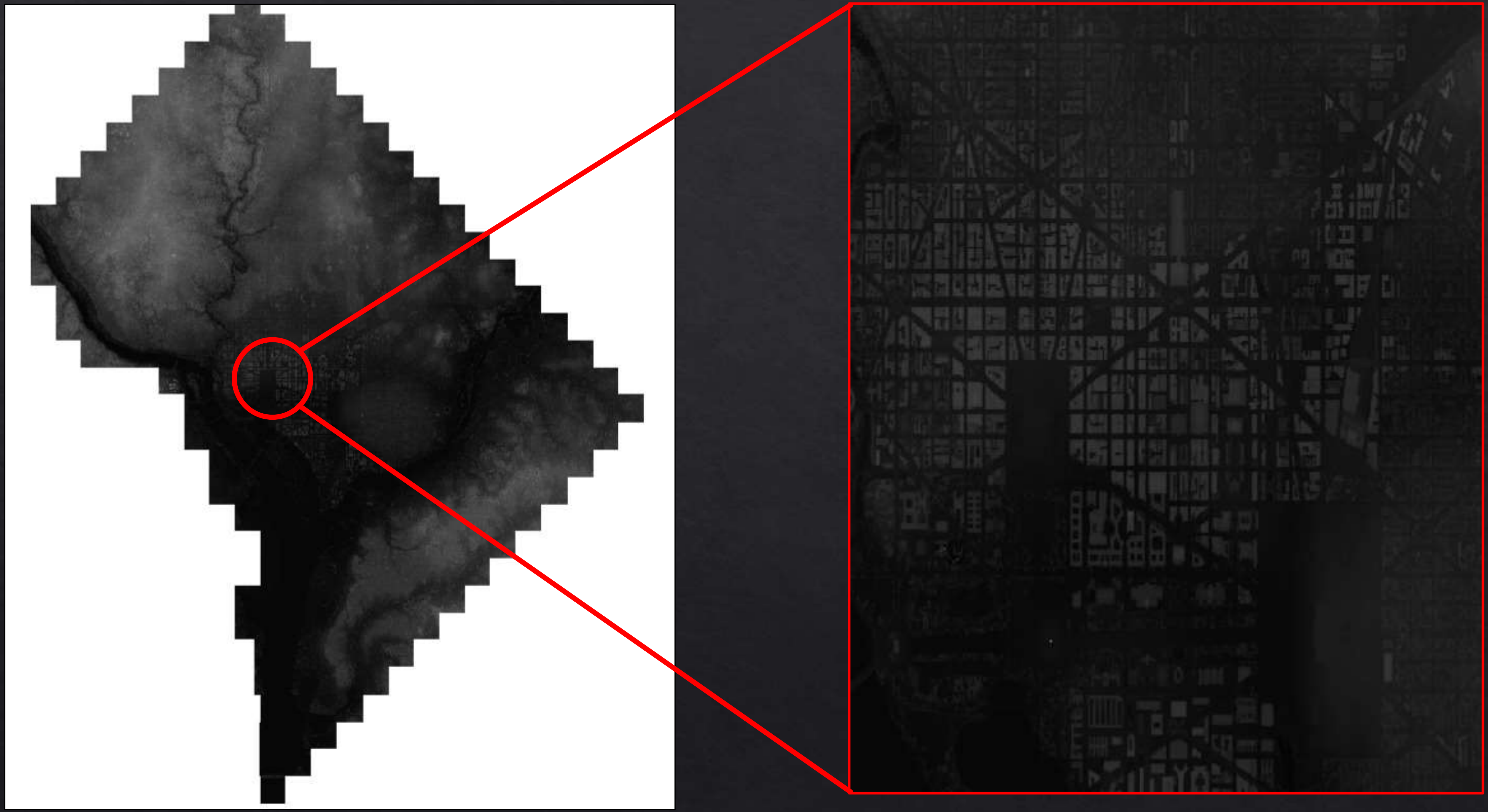
METHODOLOGY



METHODOLOGY

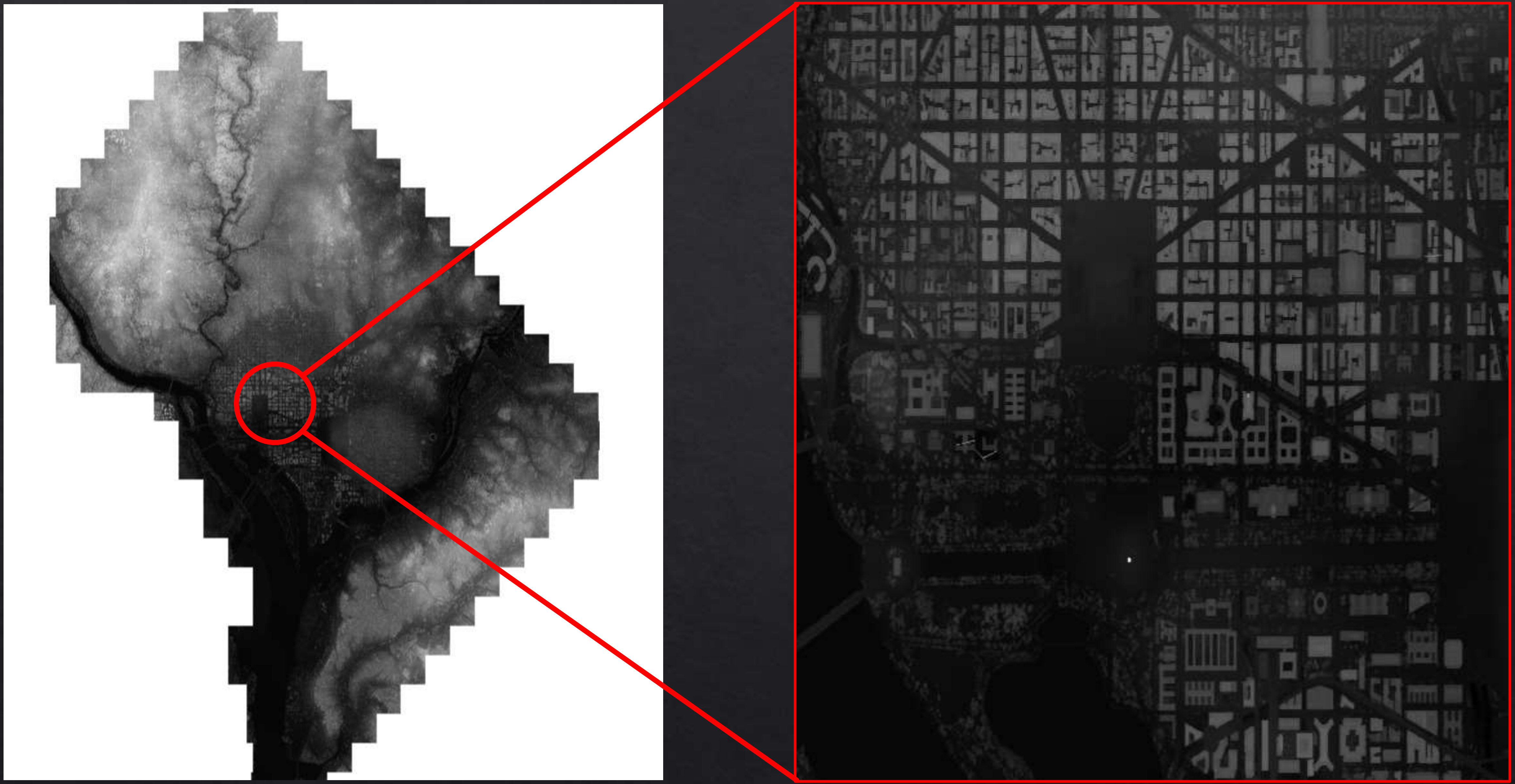
1) DSM preparation:

- Original DSM file ‘D’ is clipped/intersection/vector overlayed using the building footprints layer. ***New clipped DSM be ‘ D’ ’***. Initial attempts to clip it resulted in compatibility errors, precisely intersections in building envelopes. This was rectified by applying Fixed Geometries (a QGIS feature) to the building footprints vector layer.
- D’ is uniformly divided into 64 rectangular patches. 22 of them were found to be useless as they contained no data (this happened because original city DSM was not a perfect rectangle and its division into 64 parts caused some parts to have empty areas to have empty/no data areas too). Useful parts = 64 – 22 = 42. ***D’’ be our set of these 42 patches***.
- For each part we create Wall Height and Wall Aspect Raster using UMEP’s Urban Geometry plugin provided by QGIS. ‘H’ and ‘A’ be corresponding sets of Wall Height and Wall Aspect Raster , |H|=|A|=42
- Some cells in D’’ were mixed i.e., they had empty space + buildings/features which causes some cells in H to have value of order 1e9. These values if kept would cause integer overflow in further computations. Using Raster calculator we replace cell values >1000 with 0. Thus we get ***H’ and A as the set of Wall Height and Aspect Rasters.***

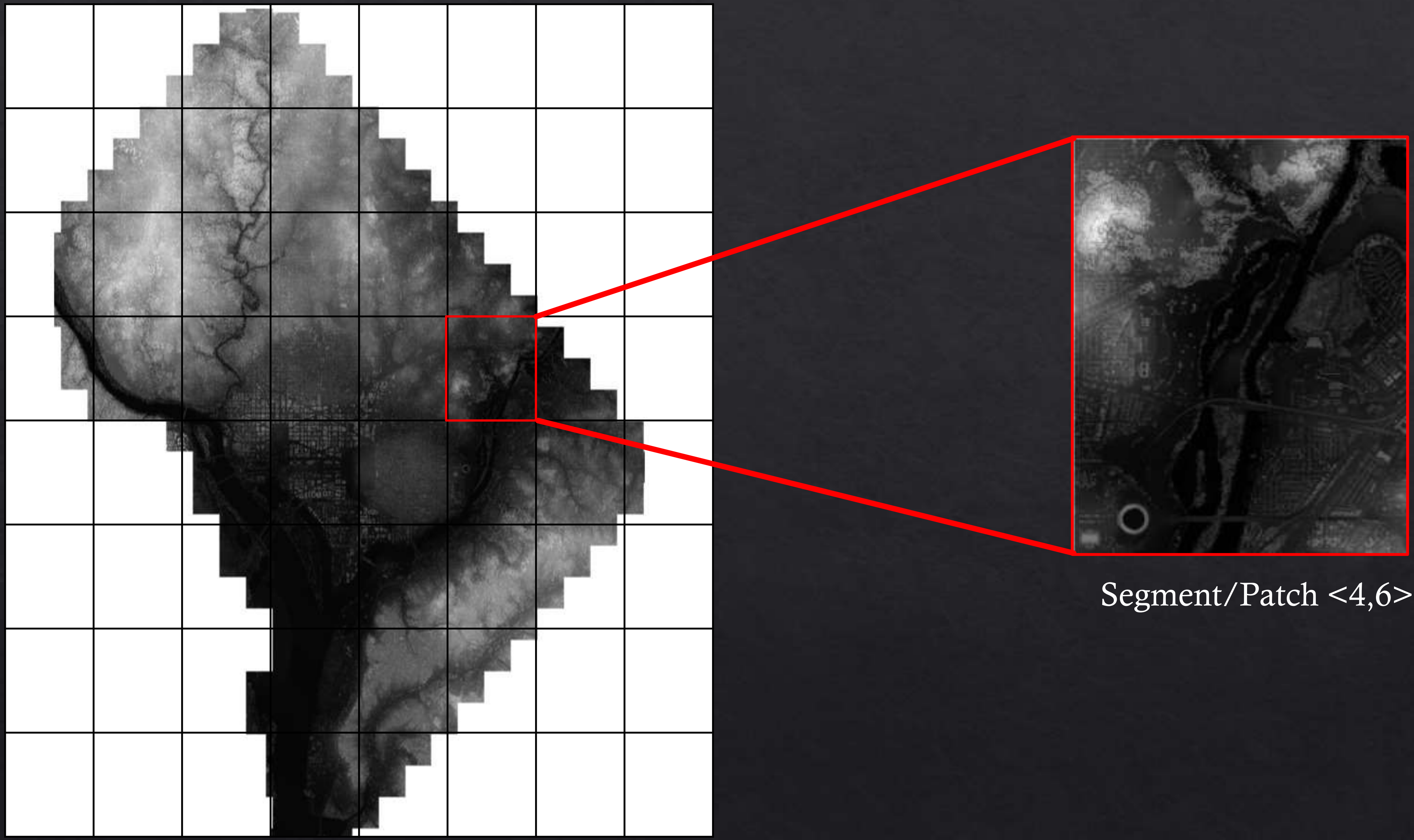


D, the raw DSM

Building footprints vector layer

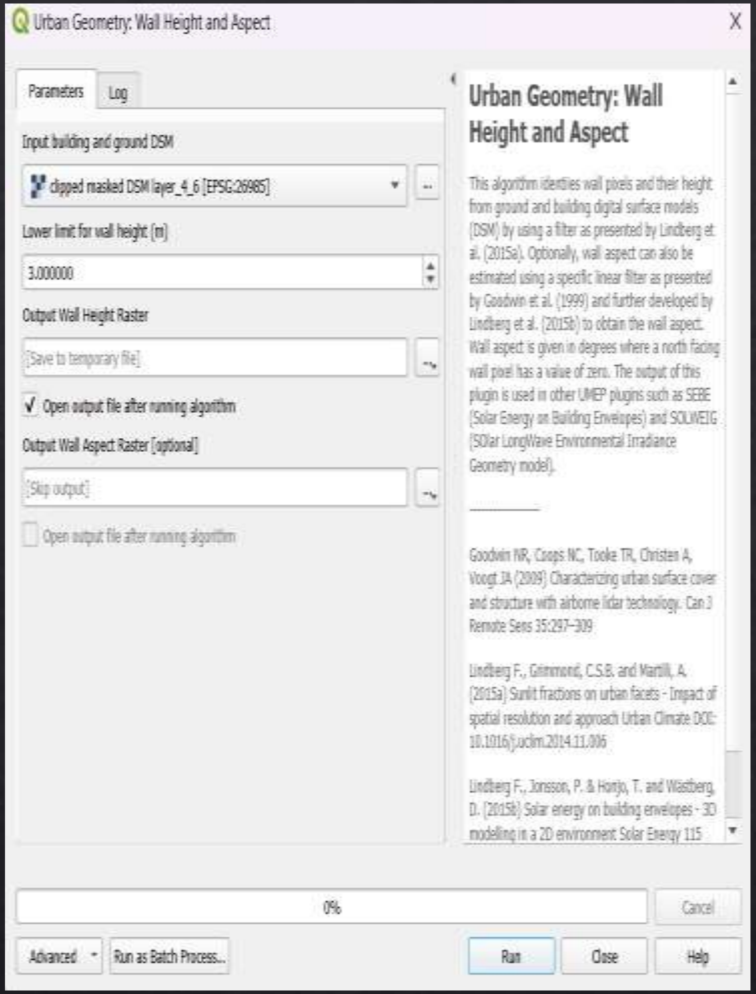


D’



Segment/Patch <4,6>

D’’



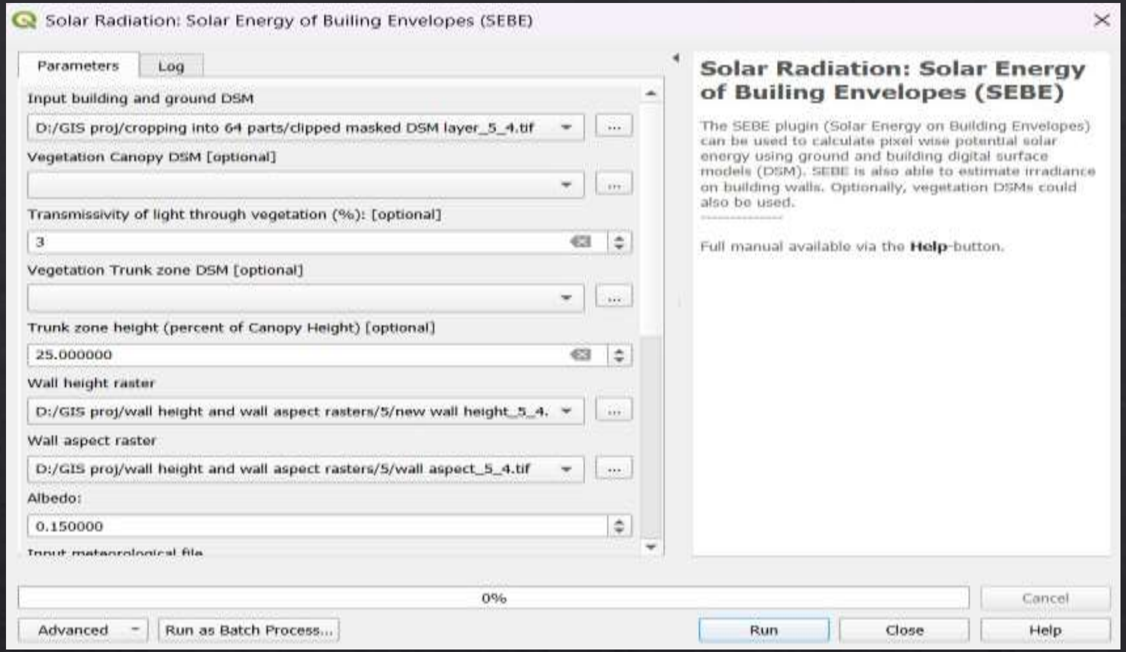
Wall Height raster for <4, 6>

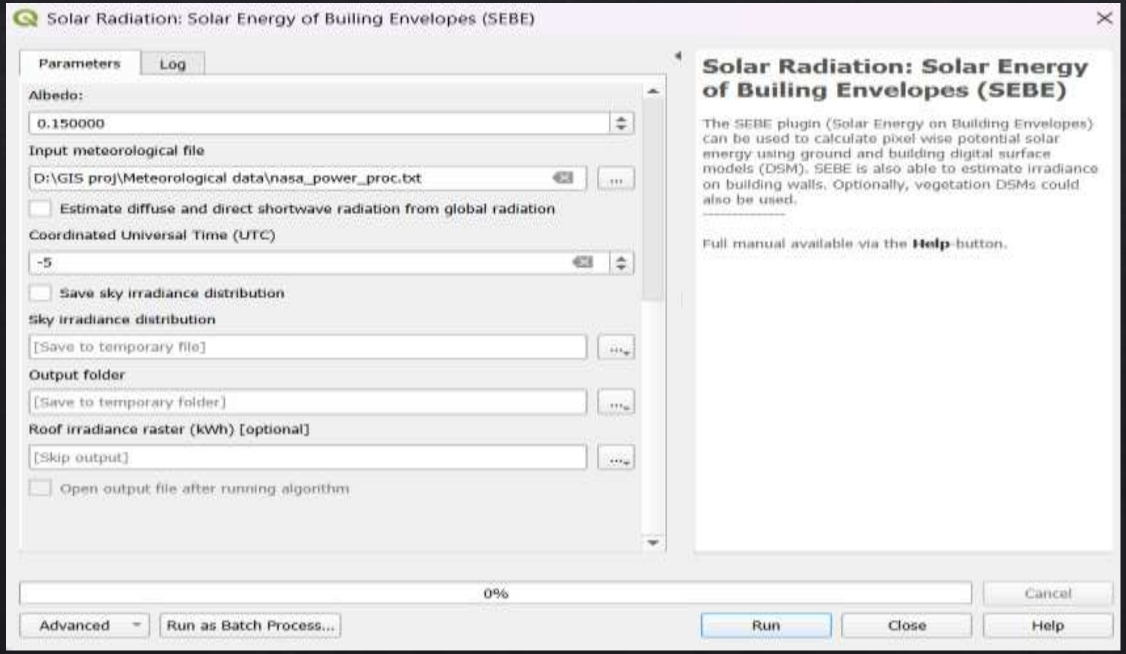
Wall Aspect raster for <4, 6>

METHODOLOGY

2) Running SEBE Model:

- SEBE model is provided by UMEP.
- We run the model for each of the 42 patches.
- Meteorological data obtained from NASA Power DAV be ‘M’.
- Time zone is set to UTC-5. Rest all parameters like albedo are left as default.
- For each patch, parameters needed:
  - Ground DSM ϵ D’’
  - Corresponding Wall Height Raster ϵ H’
  - Corresponding Wall Aspect Raster ϵ A
  - Meteorological data M
- After running the model, for each patch we get data for ***Solar Energy received per square meter***. Call this set as ‘S’, |S|= |D’’|.



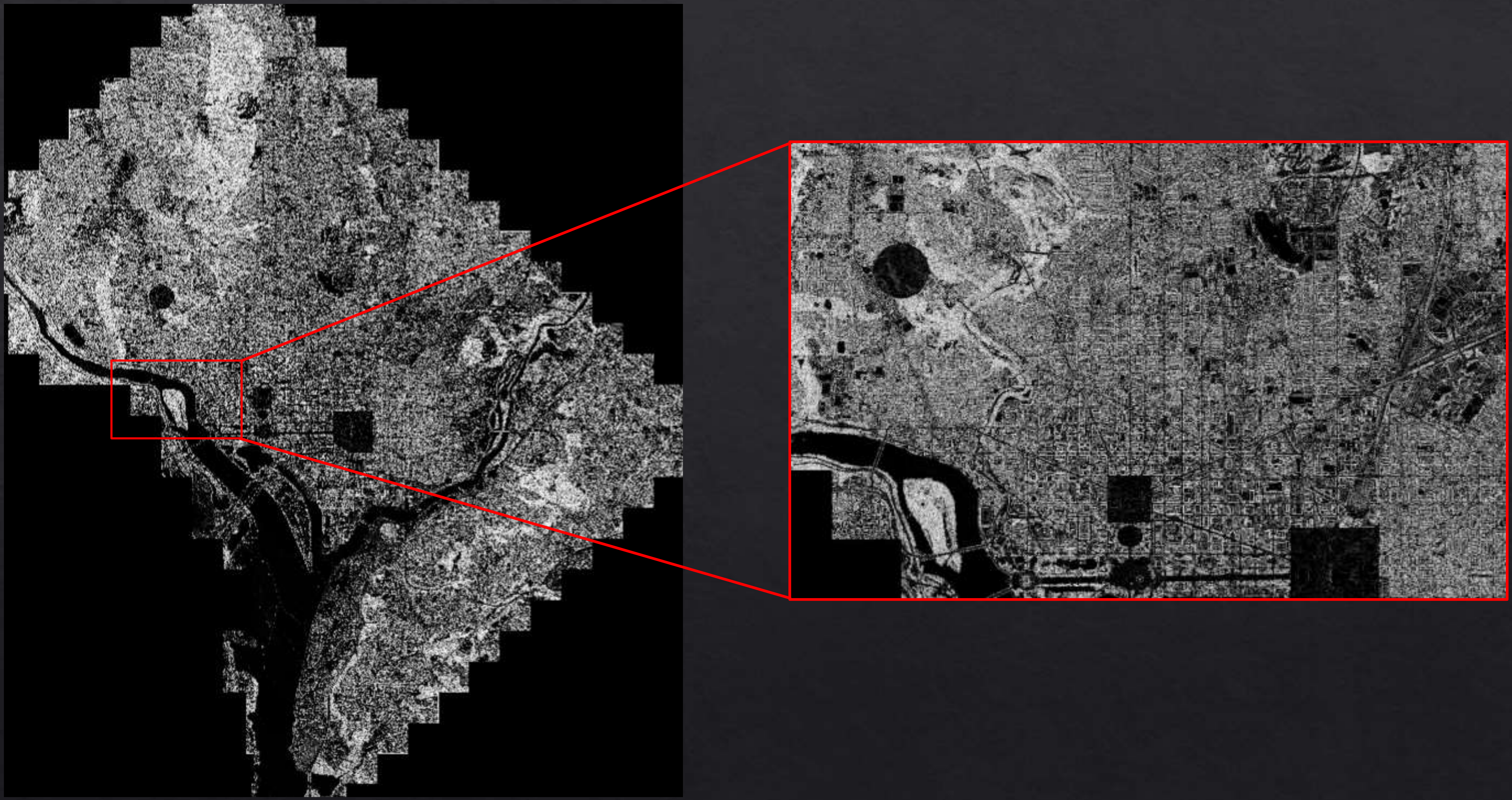


x = Output of the SEBE, $x \in S^*$

METHODOLOGY

3) Roof refinement of rasters:

- We merge the patches in D’’ ⟶ D*, S ⟶ S*.
- We calculate slope raster on D* ⟶ R* (functionality for this provided by QGIS).
- For each building envelope, if slope = x then:
  - Corresponding cell values in S* ⟶ value * factor, if $x \leq 65$ degrees to account for true area
  - No change, if $x > 65$ degrees.
- This leaves us with our final solar energy per square meter rasters S*.

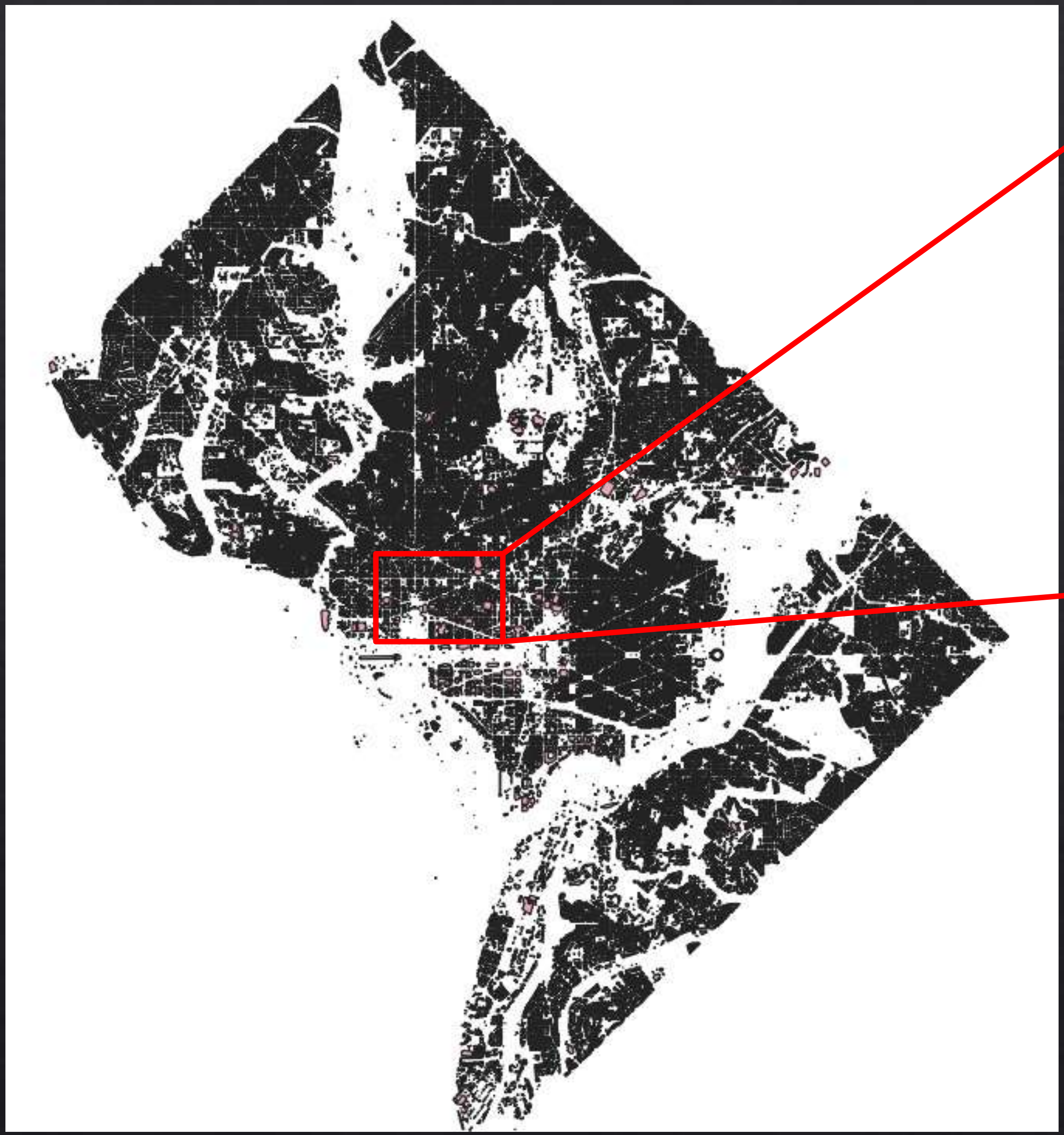


Slope raster R*

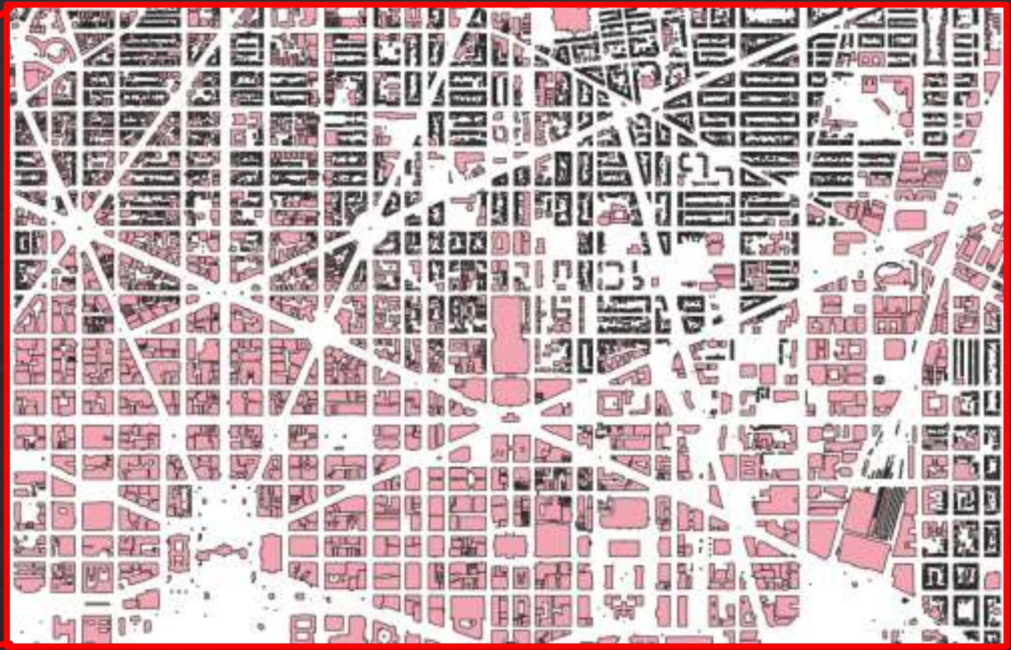
METHODOLOGY

4) Dissemination of output data and knowledge:

- We use Zonal Statistics, a geo-package which can be represented as vector layer, along with an associated attribute table.
- We run a query on this table to sum values for each building and get the total energy generation capacity for the city.
- The vector layer has been encoded with a colorbar for visualization.

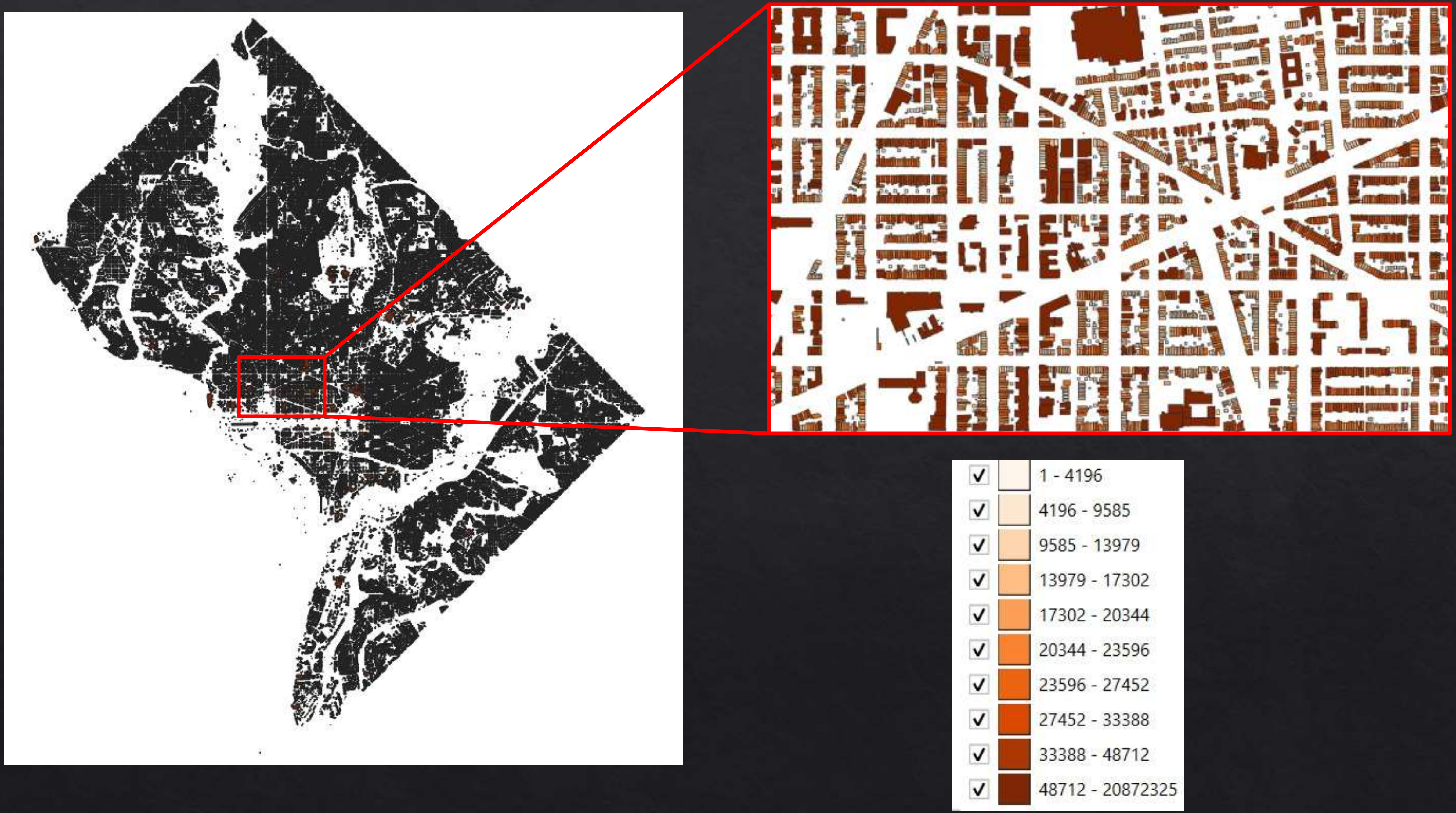


Zonal statistics for S*



	fid	FEATURECOD	DESCRIPTIO	CAPTUREYEA	CAPTUREACT	GIS_ID	OBJECTID	_count	_sum	_mean
1	28014	2000	Building	23-04-2019	E	BldgPly_28014	28014	48815	20873324.8906...	427.580147305...
2	3244	2000	Building	23-04-2019	E	BldgPly_3244	3244	44292	15381889.7069...	347.509475909...
3	8421	2000	Building	10-05-2023	U	BldgPly_8421	8421	41723	14471095.9170...	346.837377674...
4	3682	2000	Building	24-04-2015	E	BldgPly_3682	3682	28810	12811141.3008...	444.676893467...
5	94516	2000	Building	11-03-2021	E	BldgPly_94516	94516	29679	12030151.0456...	405.342196356...
6	5618	2000	Building	11-03-2021	E	BldgPly_5618	5618	31888	11351102.7418...	355.956252487...
7	3692	2000	Building	10-05-2023	U	BldgPly_3692	3692	36360	10712716.6271...	294.629170162...
8	6025	2000	Building	11-03-2021	E	BldgPly_6025	6025	36000	10643721.8981...	295.593254225...
9	3691	2000	Building	23-04-2019	E	BldgPly_3691	3691	28333	10477345.3137...	369.793008638...
10	3672	2000	Building	09-03-2017	E	BldgPly_3672	3672	19767	10336292.6623...	522.906493768...
11	3194	2000	Building	24-04-2015	E	BldgPly_3194	3194	25187	10285587.0328...	408.368882075...
12	2885	2000	Building	09-03-2017	E	BldgPly_2885	2885	18001	9851657.33103...	510.480992108...
13	3177	2000	Building	24-04-2015	E	BldgPly_3177	3177	25790	9428229.37648...	365.576843640...
14	3680	2000	Building	09-03-2017	E	BldgPly_3680	3680	18566	8949486.42107...	481.517724151...
15	3006	2000	Building	09-03-2017	E	BldgPly_3006	3006	14888	8393046.31738...	563.745722553...
16	101096	2000	Building	10-05-2023	U	BldgPly_101096	101096	28543	8208941.70108...	287.599120663...
17	4817	2000	Building	23-04-2019	E	BldgPly_4817	4817	19355	8180980.12241...	422.680460967...
18	7152	2000	Building	24-04-2015	E	BldgPly_7152	7152	18062	8048639.95002...	445.667144171...
19	6027	2000	Building	24-04-2015	E	BldgPly_6027	6027	18263	8035156.74958...	439.969268445...
20	6023	2000	Building	24-04-2015	E	BldgPly_6023	6023	24925	7937516.14645...	318.456013899...
21	3070	2000	Building	24-04-2015	E	BldgPly_3070	3070	22366	7935512.64442...	354.770772729...
22	101095	2000	Building	10-05-2023	U	BldgPly_101095	101095	32268	7766488.20677...	240.687002813...
23	3693	2000	Building	23-04-2019	E	BldgPly_3693	3693	20756	7729382.31944...	372.392872935...
24	14520	2000	Building	24-04-2015	E	BldgPly_14520	14520	16486	7108785.62242...	431.724986179...

Attribute table


1 - 4196
4196 - 9585
9585 - 13979
13979 - 17302
17302 - 20344
20344 - 23596
23596 - 27452
27452 - 33388
33388 - 48712
48712 - 20872325

RESULTS

1) We run a query that sums up the capacity values for each building values for each building.
2) The result of the query is 7502752079.266063 kWh = 7.503 x 1e12 Wh = 7.503 TWh.
3) Latest data on solar energy generation in Washington D.C. is of year 2022. The total energy generated via solar harnessing was 0.231 TWh (Fig. 1).
4) Results of analysis make it clear that solar energy harnessing can be boosted upto more than **32 times of the present capacity**.
5) Currently the total energy generation(non-renewable + renewable) is 0.403 TWh. Solar energy makes 57.32% of it (Fig. 2).
6) When we put (4) in context with (5), the goal of achieving 100% renewable energy generation looks quite feasible. Also it reveals how solar energy will play a significant role in achievement of the goal.

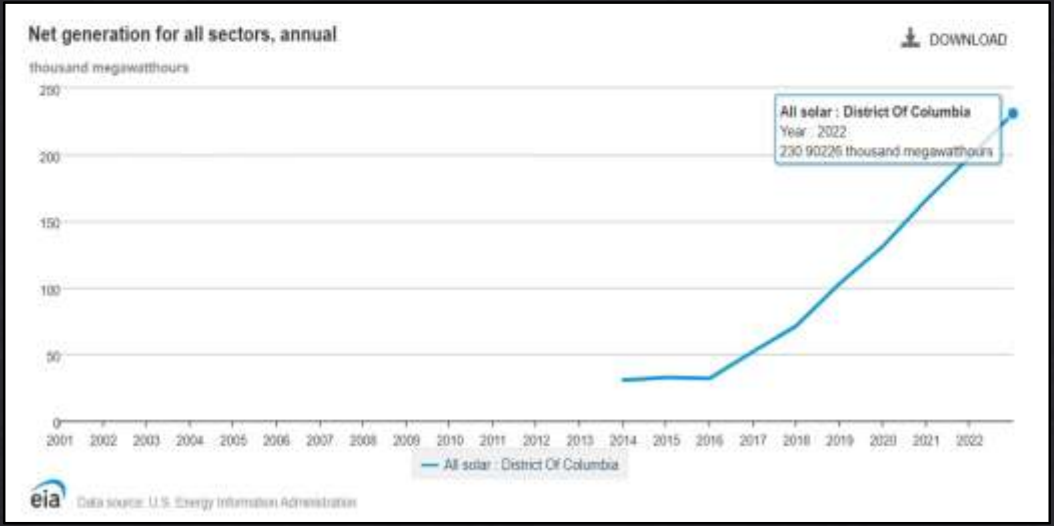
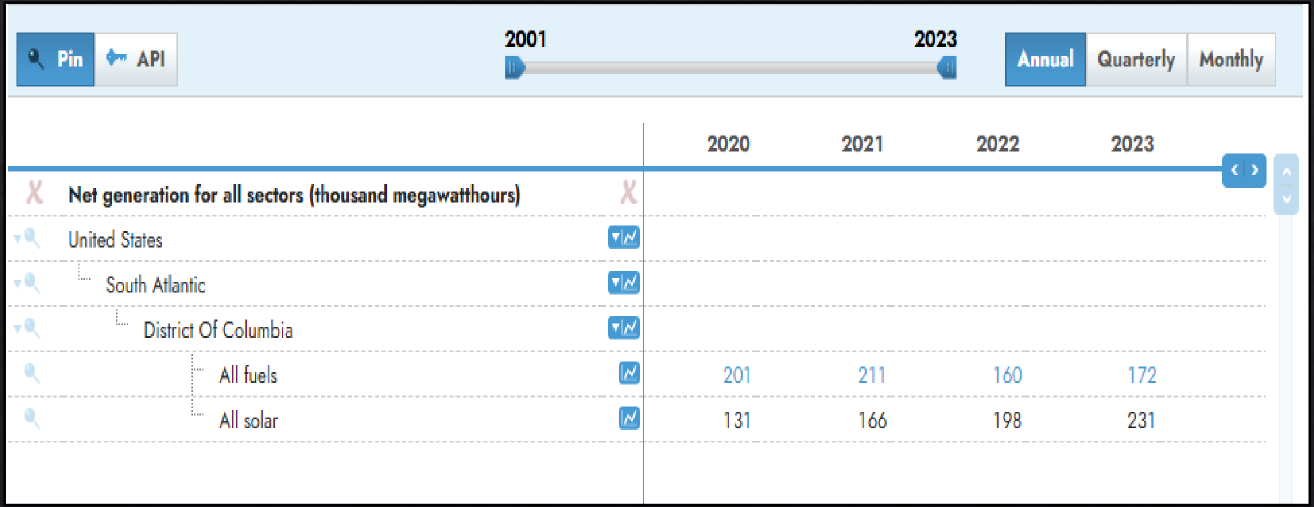


Fig. 1



Net generation for all sectors (thousand megawatthours)	2020	2021	2022	2023
United States				
South Atlantic				
District Of Columbia				
All fuels	201	211	160	172
All solar	131	166	198	231

Fig. 2

Source: CLICK HERE

CHALLENGES FACED

1) Initially we faced problems with calculations of Wall Height and Wall Aspect rasters where in we fed the full DSM file at once. After several failed trials of 15-21 hours of model running, we figured out that the error was due systems inability to allocate a huge chunk of memory for an array.
   Solution: We clipped the DSM raster using building footprints vector layer which reduced the number of data points and further split it into 64 uniform patches to reduce the size.
2) Dut to poor documentation of SEBE model, we struggled with the errors in the format of meteorological data for quite some time.
   Solution: Going through the source code of SEBE model, we found out that the model was hardcoded for a specific format of input in the meteorological data. The code was then modified to fit our format of data.
3) When we clip the DSM layer D with building footprints, raster cells lying within building envelop retain their respective values but the cells outside of building envelop get NaN values. These NaN values hinder computations in SEBE.
   Solution: These NaN values in D' are replaced with -999999. These values are very small and thus ignored by SEBE. Our objective to have solar irradiance for building roofs is now fulfilled.