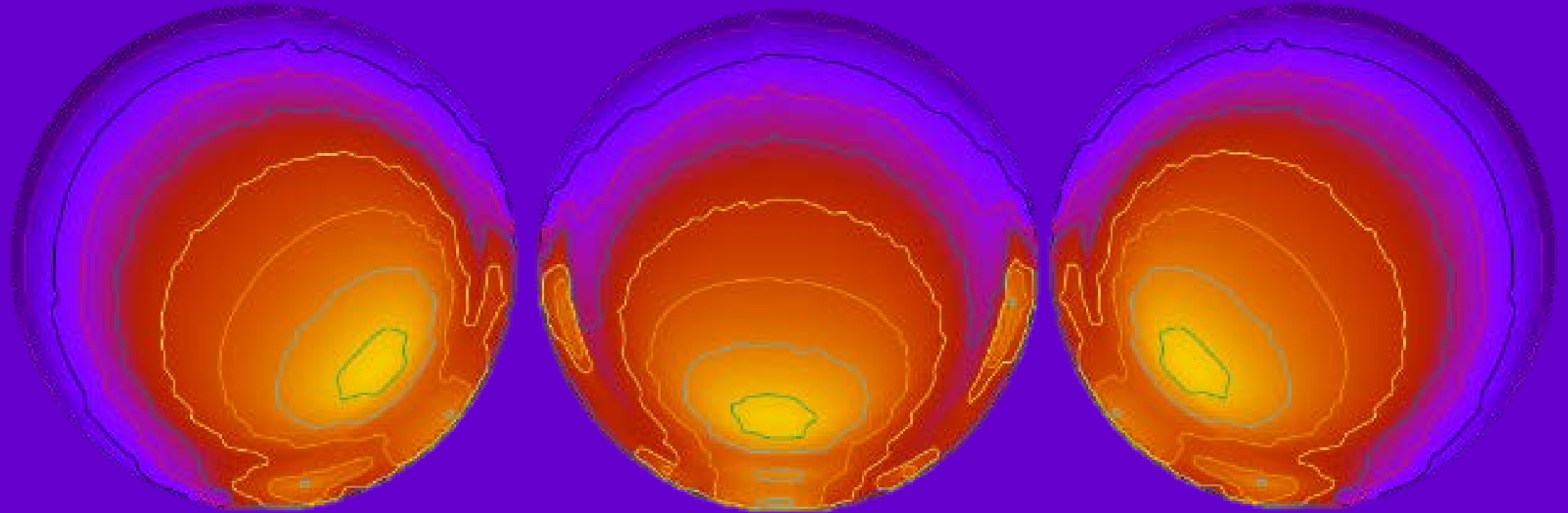


The Impact of LED Street Lighting: Relative Quantification + Real-World Comparison

U.S. DEPARTMENT OF
ENERGY | Energy Efficiency &
Renewable Energy



DOE SSL Technology Development Workshop

November 17, 2016

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Intention Behind Current Study

Blue Light

Perceived impact of
'blue rich' light

visual acuity

light scattering

circadian rhythm entrainment

environmental influence

Increased prevalence of
'blue rich' sources

reduced energy use

improved color rendition

high precision of optical control

potential control strategies

Impact of LED Street Lighting

How currently quantified

often oversimplified

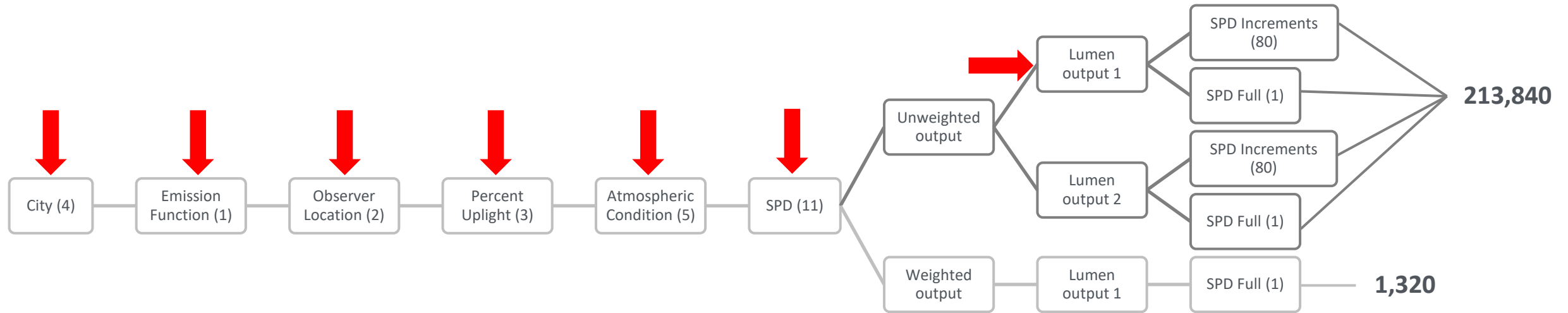
all factors held constant

Improvement in quantification

represent real-world scenarios

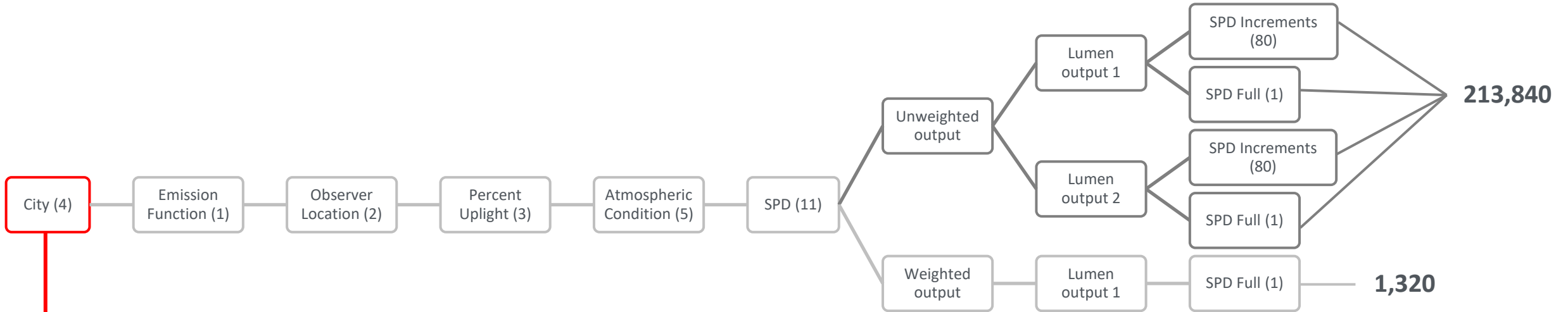
isolate variables relative impact

Experimental Design



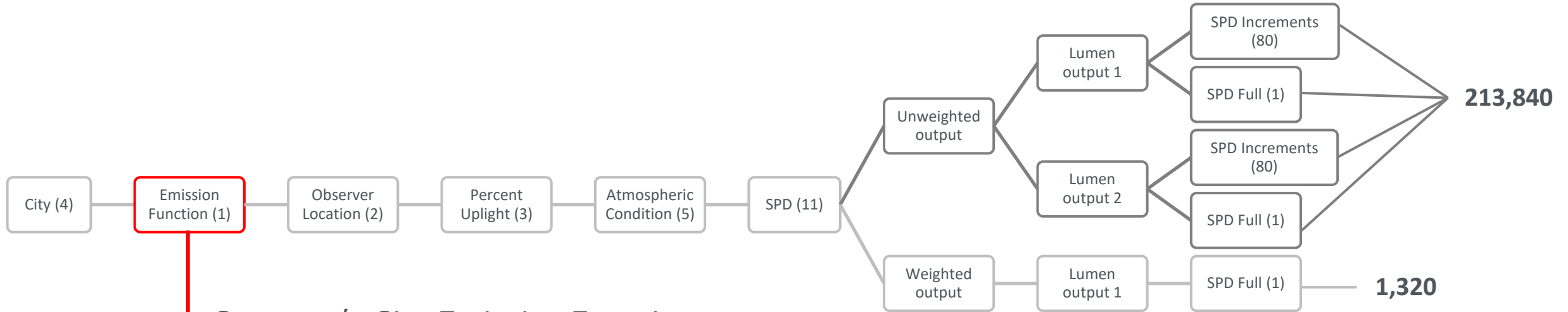
Based on predominant contribution factors to sky glow

Light Emitting Area: City



City	City Area (km ²)	Radius (km)	Population	No. Fixtures	Lighting density (Fixtures per Area)
CITY1	7	1.4	3,407	342	52
CITY2	164	7.2	76,000	3,500	21
CITY3	232	8.6	617,594	39,884	172
CITY4	28,120	94.6	9,729,825	350,000	12

Light Emitting Function



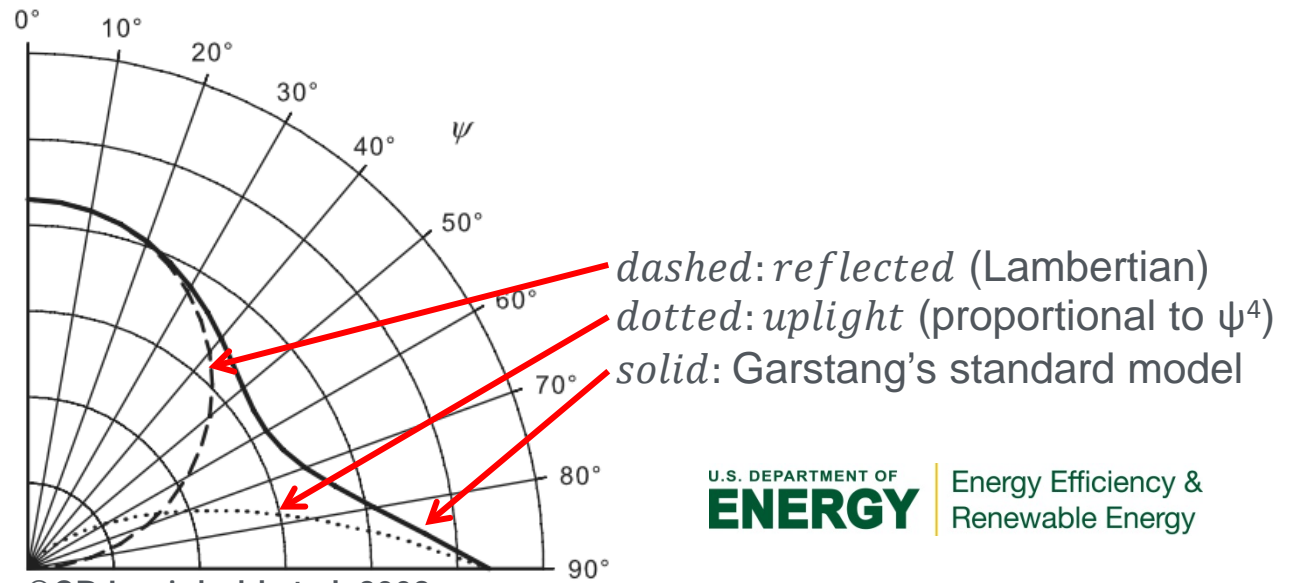
Garstang's City Emission Function

$$B(Q, q, z_0) = 2Q(1 - q) \cos z_0 + 0.554qz_0^4$$

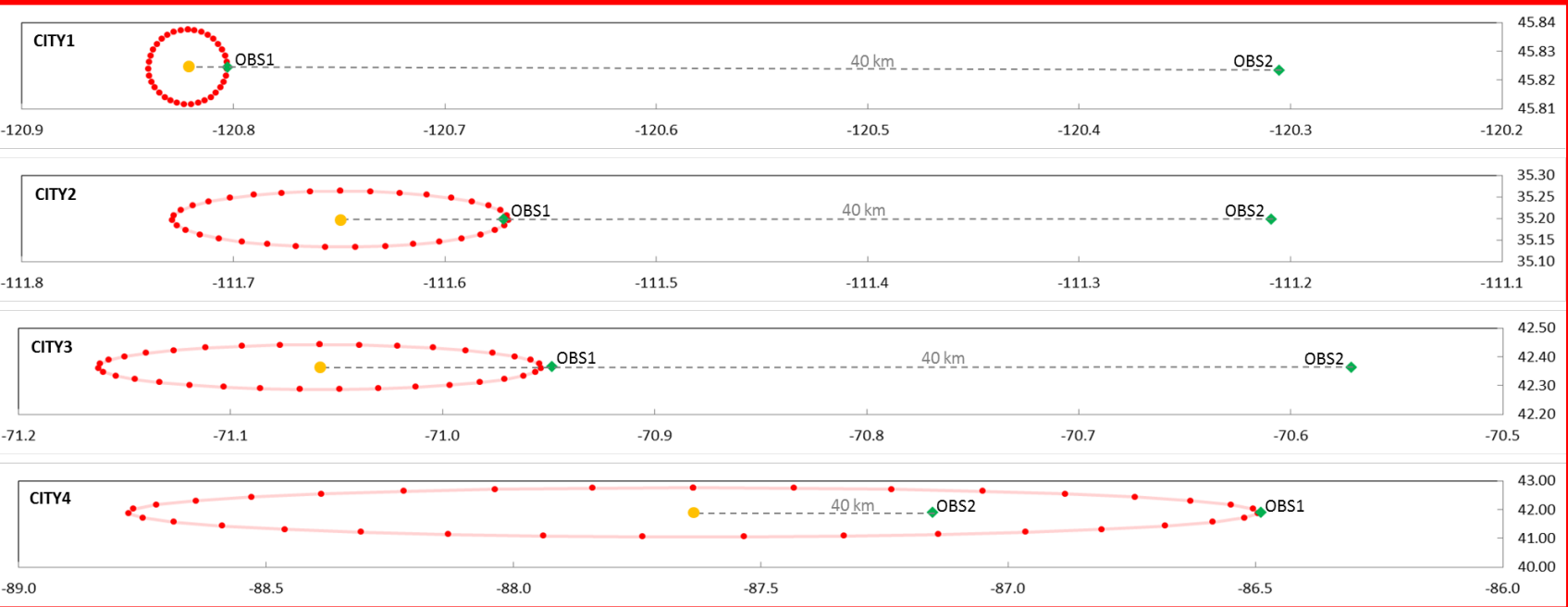
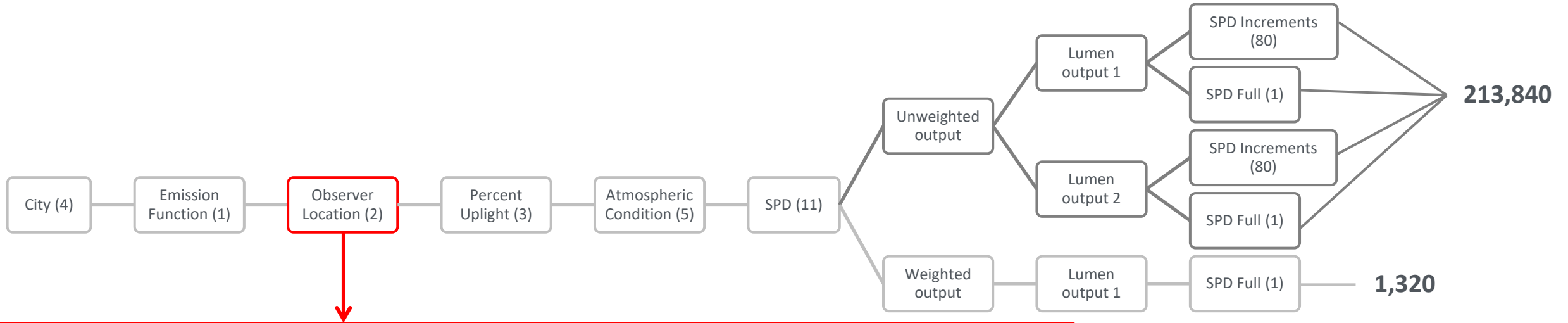
15% ground reflectance

percent downlight

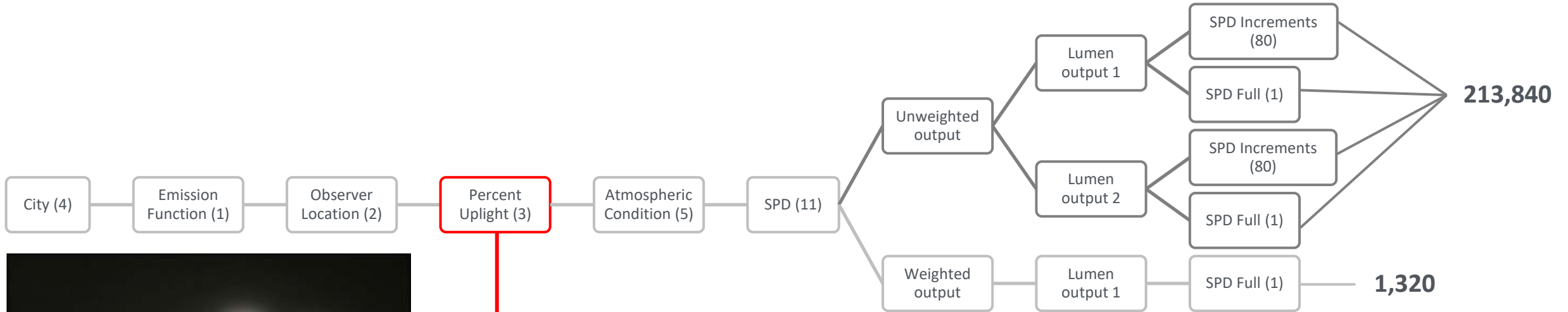
percent uplight



Location of Observer



Luminaire Uplight Percentage

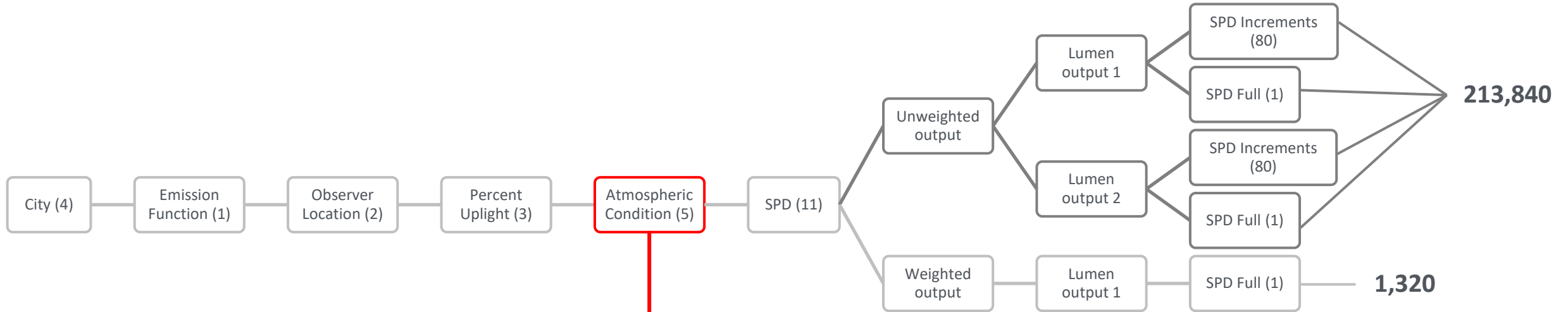


$$B(Q, q, z_0) = 2Q(1 - q) \cos z_0 + 0.554qz_0^4$$

percent uplight: 0%, 5%, 10%

- Full cut-off fixtures
- Drop-lens cobrahead
- Good quality acorn-top

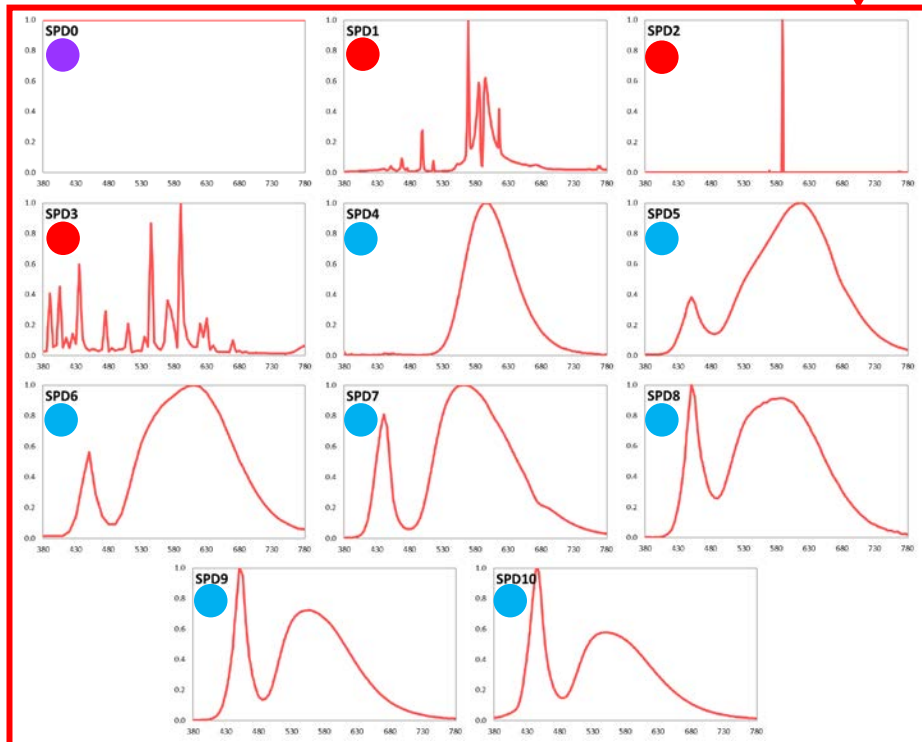
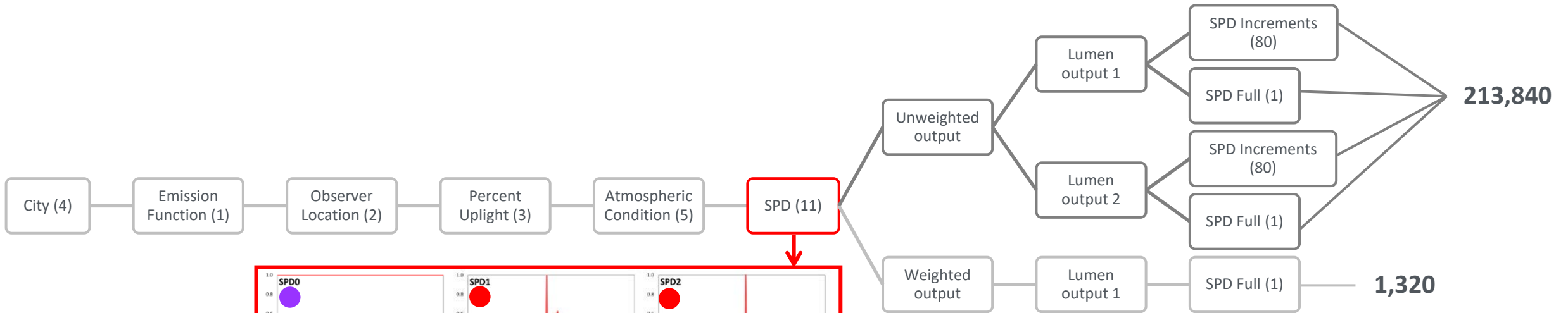
Atmospheric Condition



Atmospheric conditions		ATM1	ATM2	ATM3	ATM4	ATM5
Clouds	Cloudless	Yes	Yes	Yes	Yes	No
Cloudy	Altitude of the cloud base (km)	N/A	N/A	N/A	N/A	1
	Spectral albedo (select data file)	N/A	N/A	N/A	N/A	Altocumulus.cld
Aerosols	Reference aerosol optical thickness at 500 nm	0.1	0.1	0.5	0.5	0.5
	Angstrom exponent	0.3	1.5	0.3	1.5	1.0
	Scale height for the molecular atmosphere (km)	8.0	8.0	8.0	8.0	8.0
	Vertical gradient of the aerosol concentration (1/km)	0.65	0.65	0.65	0.65	0.65
Data files for	Single scattering albedo	constant_background.ssa				
	Asymmetry parameter	constant_background.ssa				
Horizon	Light blocking objects near horizon	none				

AERONET station data: http://aeronet.gsfc.nasa.gov/cgi-bin/type_piece_of_map_opera_v2_new?long1=-180&long2=180&lat1=-90&lat2=90&multiplier=2&what_map=4&nachal=1&formatter=0&level=1&place_code=10&year=116&place_limit=

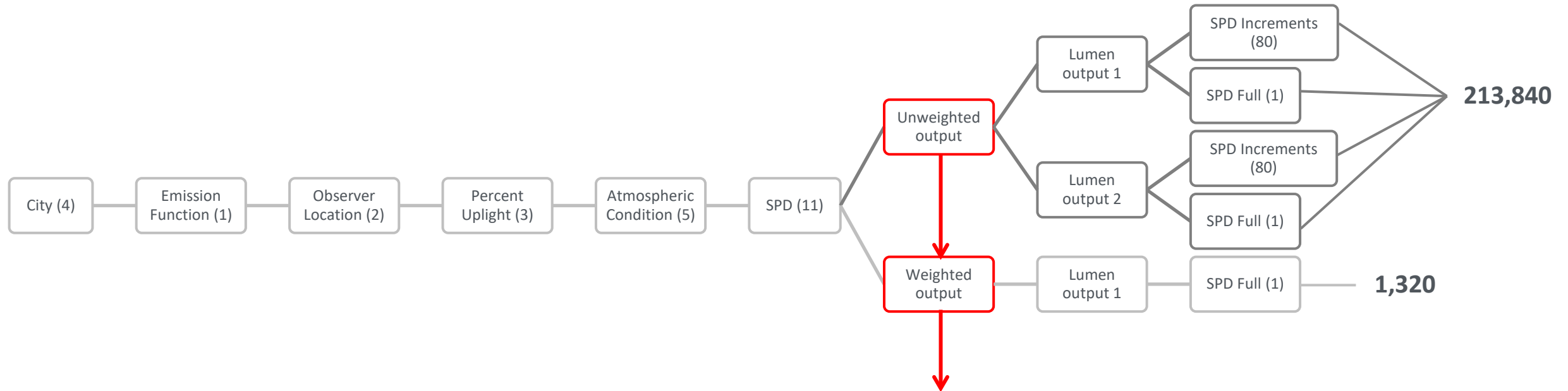
Lamp Spectral Power Distribution



- SPD0 ● Equal Energy
- SPD1 ● 2041 K High-Pressure Sodium (HPS)
- SPD2 ● 1778 K Low-Pressure Sodium (LPS)
- SPD3 ● 3924 K Metal Halide (MH) 100W
- SPD4 ● 1872 K PC Amber LED
- SPD5 ● 2704 K PC LED
- SPD6 ● 2981 K PC LED
- SPD7 ● 3940 K PC LED
- SPD8 ● 4101 K PC LED
- SPD9 ● 5197 K PC LED
- SPD10 ● 6101 K Exterior LED Flood

	S/P Ratio	S/P Rel. to HPS
SPD0	2.27	5.28
SPD1	0.43	1.00
SPD2	0.21	0.49
SPD3	0.95	2.21
SPD4	0.41	0.96
SPD5	1.16	2.70
SPD6	1.17	2.73
SPD7	1.24	2.90
SPD8	1.58	3.69
SPD9	1.54	3.59
SPD10	1.65	3.84

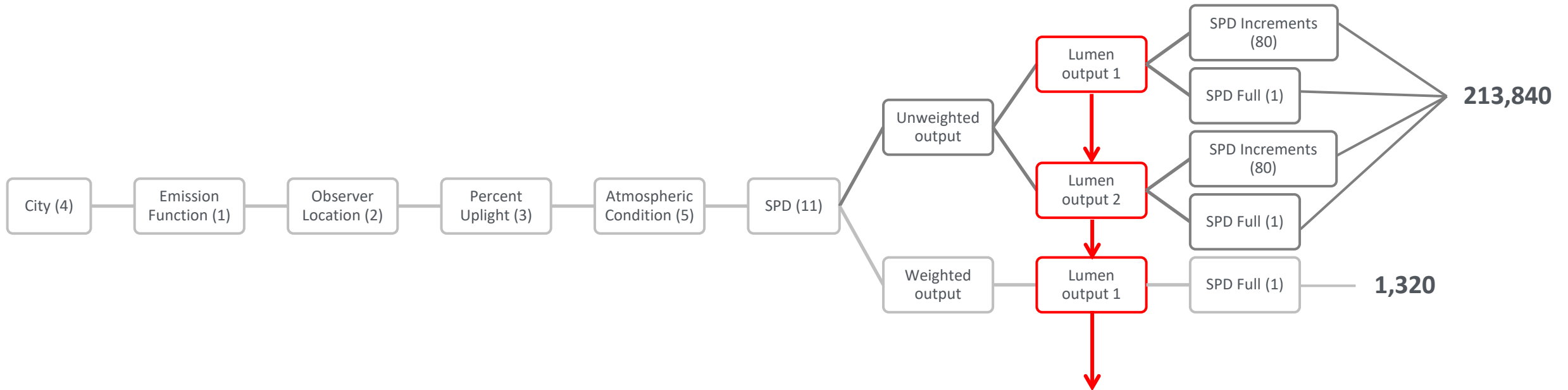
Output: Unweighted or Scotopically-Weighted



Unweighted: irradiance $\left(\frac{W}{m^2}\right)$

Weighted: scotopic illuminance $\left(\frac{cd}{m^2 sr}\right)$

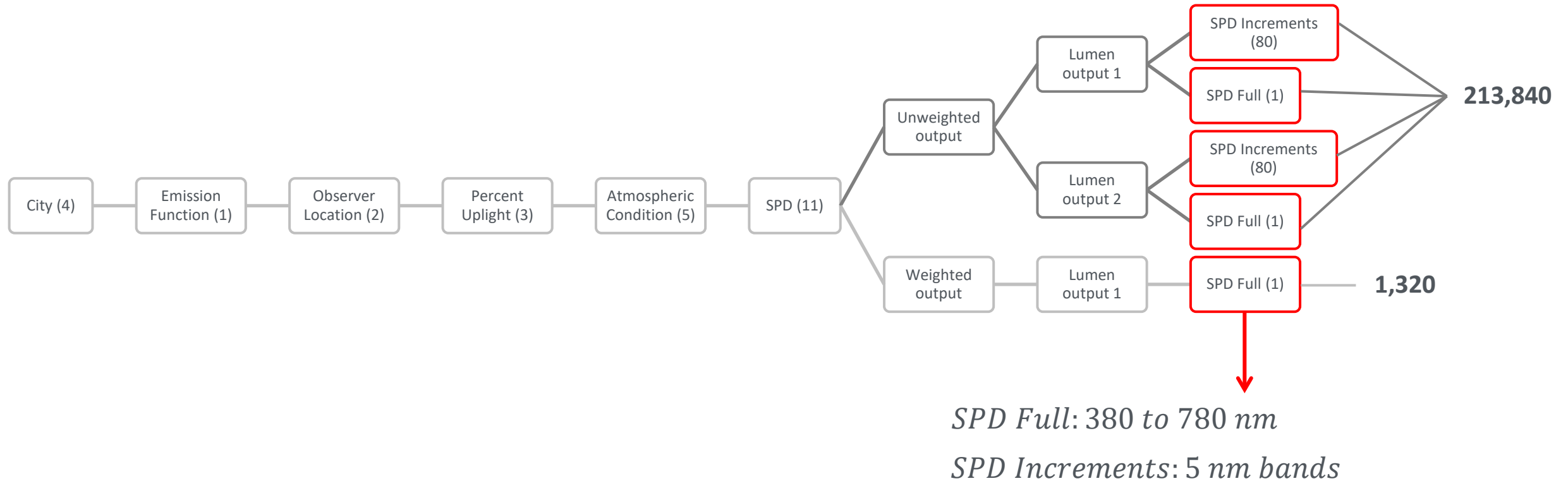
Lumen Output per Fixture



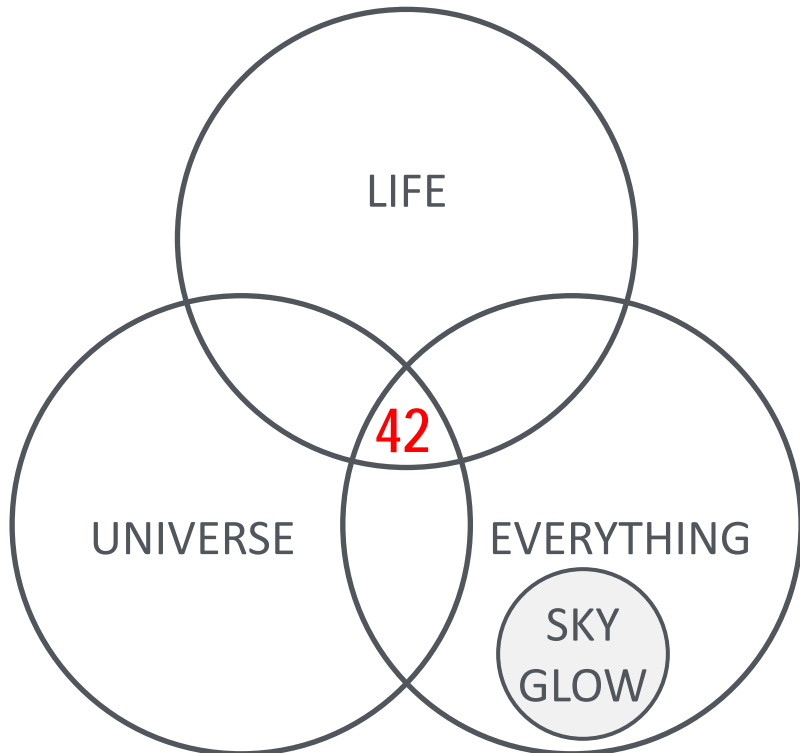
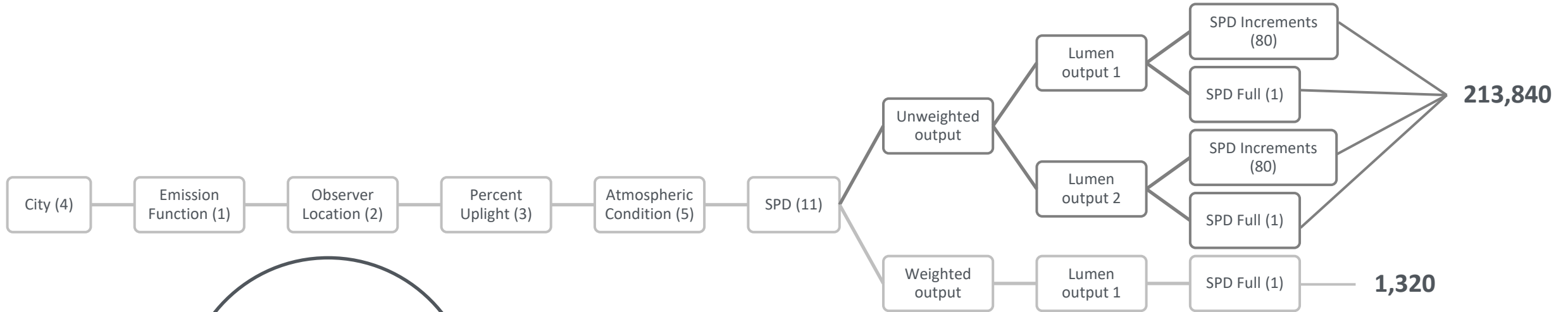
Lumen output 1: 1000 lm/fixture (HPS)

Lumen output 2: 500 lm/fixture (LED)

Wavelength Increment of Run



Results



In Context: Sources of Impact

