**INTRODUCTION**

In recent years, the climate on Earth has changed markedly: some countries suffer from abnormal heat, others from too harsh and snowy winters, unusual for these places[1]. In addition to global warming, there is also an imbalance of all-natural systems. That leads to a change in the regime of precipitation, temperature anomalies, increasing the frequency of extreme events such as hurricanes, floods, and droughts. Human influence has been the dominant cause of observed warming since the mid-20th century. Continued greenhouse gas emissions will cause further warming and changes in all components of the climate system. Obstructing climate change requires substantial and sustained reductions in greenhouse gas emissions. A solution to climate change could be to reduce greenhouse gas emissions by renouncement of fossil energy sources. The ambitious goal to free the world from fossil fuels implies the broadest use of renewable energy sources[2].

Global progress in the development of renewable energy sources is very significant. The most actively developing areas of renewable energy are solar and wind generation. The spread of innovations in renewable energy is attracting increasing attention as the primary tool to combat climate change and an opportunity to increase the competitiveness of countries in the international market.

The subject of this article is wind energy as one of the most promising renewable technology, which allows evaluating the possible future trends in renewable energy implications.

According to the BP statistical review of world energy [3], the global trend in wind energy (WE) deployment is quite optimistic (see Picture 1). Nevertheless, the share of WE is not so impressive and represents about 6% of total electricity production (see Picture 1).

*Picture 1. World’s wind energy generation and total electricity production (GWh)* [3]*.*

The International Renewable Energy Agency (IRENA), in its “Future of the Wind” [4], claims about 35% of electricity consumption to be generated from wind by 2050. However, some other prognoses [5][6] are more pessimistic and predict up to 15%, which is still quite ambitious.

The forecasting methodology of IRENA [4] has not been described, and Schalk Cloete’s prognosis [5][6] only mentioned S-curves. Thus, there is still a question about wind energy development growth by 2050.

This article aims to elucidate the prognosis by implementing “Diffusion of innovation” models [7] [8] [9][10]on the macro level. “Diffusion of innovations” [11] is one of the main theoretical approaches to understanding how new ideas, products, or services are distributed in various social systems. Many scientists have used the theory for decades. Applying this theory at different levels of analysis allows a better understanding of specific innovation pathways.

Wind energy is often recognized as an ecological innovation (EI). Thus, the first scope of this article is to check whether the diffusion of innovation models could be applied for EI predicting and provide reasonable evaluations. The other is to analyze possible trends in future wind energy development within the “Diffusion of innovations” models.

**1. METHODOLOGY**

*1.1 DATASET.*

The recent statistical review by BP [3] had been used as the dataset. The dataset contains information on total electricity consumption by countries and regions, electricity generation by sources, and installed capacities and production by renewable sources, covering years since 1995 until 2020. Five areas with wind electricity production above 50 TWh per year by 2021 were analyzed – World total, Europe, North America, South&Central America, Asia&Pacific regions.

*1.2 PRELIMINARY ASSUMPTIONS.*

Three standard models were used to provide the research: The Bass model [7], the Logistic Growth model[12], and the Gompertz model. All models were implied within three modes: the original equation, with variable upper limit and variable upper limit considering the variable costs. Models are initially described by three parameters, two of which determine the function shape, and the last one defines the boundary of process growth. Those parameters are adjusted with the least-squares criteria to minimize the difference between the model and actual data. Thus, the limit of process growth could be evaluated.

Following assumptions were applied to introduce variability into the models:

* Wind energy will take the fixed limited share of the electricity generation.

To introduce this assumption into the models, the following statement accepted:

|  |  |
| --- | --- |
|  | (1) |

*Ew* – wind generation; *t* – time; *k* – the final share of wind energy in total electricity generation; *E* – whole generation for variable upper boundary mode.

* The share depends on wind energy costs.

To introduce this assumption into the models, the following statement accepted:

|  |  |
| --- | --- |
|  | (2)  (3) |

*Ew* – wind generation; *t* – time; *k* – the share of wind energy in total electricity generation depending on wind energy costs; *E* – whole generation for varying upper boundary mode; *R* – constant, *c* – WE costs

(see Appendix A).

* The electricity generation growth is linear, and the regression estimation could be evaluated from the known dataset.

To introduce this assumption into the models, the following statement accepted:

|  |  |
| --- | --- |
|  | (4) |

*E* – total generation; *t* – time; *a,b* are the linear regression coefficients (see Appendix B).

* The decreasing cost of wind energy could be estimated with the following equation from the known dataset (see Appendix B).

To introduce this assumption into the models, the following statement accepted:

|  |  |
| --- | --- |
| + M | (5) |

*c* – wind energy costs; *K, L* – exponential regression coefficients, *M* – the lowest boundary

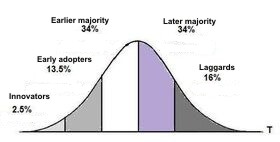
(see Appendix C).

*1.3 MODELS DESCRIPTION.*

***The Logistic Growth model:***

***Description***

In his work “Diffusion of Innovation” [10], Rogers investigated the adoption rates of various innovations. He found that most of the graphs of innovation adoption by members of society resemble a standard bell curve divided into five parts (Pictures 2,3).



**Picture 2. Time distribution of the innovation adopters [10].**



**Picture 3. Total number of adopted innovations** [11]**.**

Total innovation volume represents the typical “S-curve,” which could be described with numerous equations. One of the most known is the “Logistic Growth.”

Basic equation:

|  |  |
| --- | --- |
| Y | (9) |

Where Y(t) – wind generation at period t; Xmin – Wind generation at the first point; M – Upper limit of generation growth since the first known number; l and – coefficients, determining the curve shape.

Variable upper limit:

|  |  |
| --- | --- |
| Y | (10) |

Where *Y(t)* – wind generation at period t; *Xmin* – Wind generation at first point; M(t-1) = the total electricity generation in the previous year; *k* – the achievable wind energy generation share; *l* and – coefficients, determining the curve shape.

Variable upper limit considering variable costs:

|  |  |
| --- | --- |
| Y | (11) |

Where Y(t) – wind generation at period t; Xmin – Wind generation at first point; M(t-1) = the total electricity generation in the previous year, R – the price curve coefficient, ct-1 – costs per 1 KWh during the last year, k, – coefficients, determining the curve shape.

***The Bass model.***

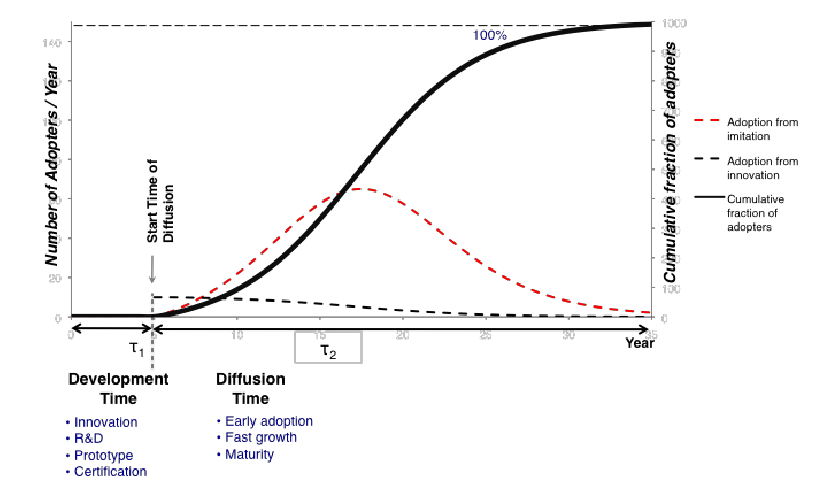
***Description.***

The essence of the Bass model [7] is that two categories explain the growth in the number of consumers of an innovative product:

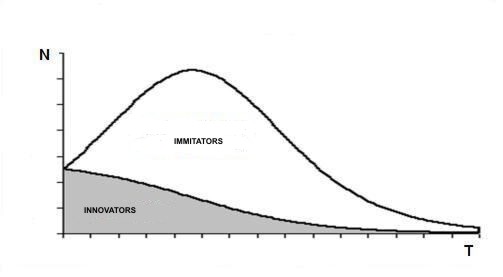
• Those who try a new product themselves in the first place - innovators;

• Those who learn about a new product from the first category - imitators.

At the initial stage of the product life cycle, the innovators prevail. As the number of adopters grows, the effect of imitators increases. The model illustrates well the principles of reinforcing feedback (the number of consumers of a product increases the flow of new consumers due to interpersonal communication). Unlike Rogers, Bass identified not five but only two categories of people (see Picture 4,5).

****

**Picture 5. Total number of adopted innovations** [16]**.**



**Picture 4. Time distribution of the innovation adopters** [16]**.**

The Bass Model describes sales at the period, which are the derivative from the distribution. Following original equation [7] had been used.

Basic equation:

|  |  |
| --- | --- |
|  | (6) |

Where S(t) – sales at period t; – cumulative sales through the period [0 ... t - 1]; p – coefficient of innovation, q – coefficient of imitation, m – the total number of all purchasings.

Variable upper limit:

|  |  |
| --- | --- |
|  | (7) |

Where S(t) – sales at period t; – cumulative sales through the period [0 ... t - 1]; p – coefficient of innovation, q – coefficient of imitation, Mi = the total electricity generation in the previous year, k – the share limit of wind energy in the total electricity production.

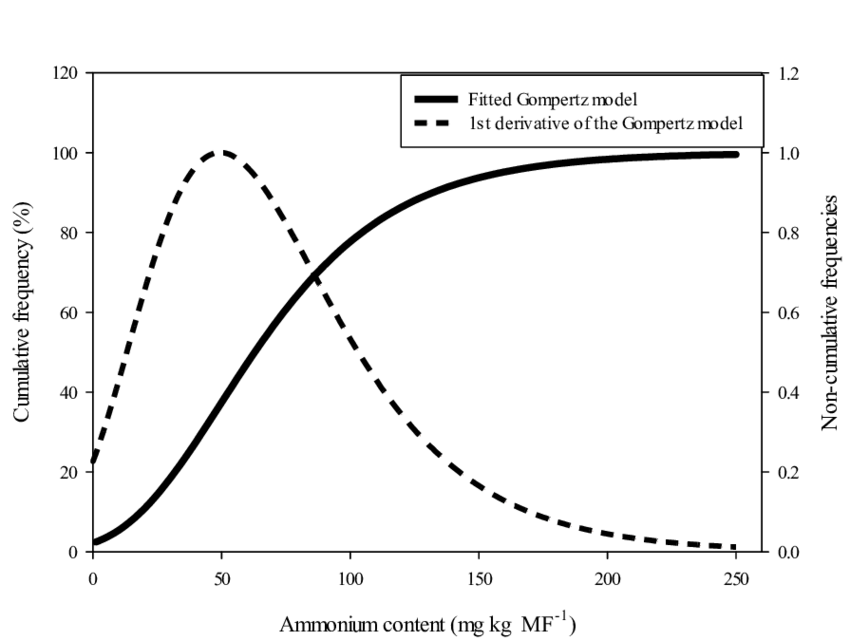
Variable upper limit considering variable costs:

|  |  |
| --- | --- |
|  | (8) |

Where S(t) – sales at period t; – cumulative sales through the period [0 ... t - 1]; p – coefficient of innovation, q – coefficient of imitation, M(t-1) = the total electricity generation in the previous year, R – the price curve coefficient, ct-1 – costs per 1 KWh in the previous year.

***The Gompertz model:***

This is a type of mathematical model for time series where growth is slower at the beginning than at the end of the period (see picture 6,7). It resembles a logistic curve but is not symmetrical. The deceleration does not occur as fast as its acceleration. The Gompertz model [13] [14], successfully applied to different growth processes evaluation [15][16]. In some cases, Gompertz distribution shows better results than logistic growth models.



**Picture 6. Gompertz model and the first derivative example .**

Basic equation:

|  |  |
| --- | --- |
| Y | (12) |

Where Y(t) – wind generation at period t; Xmin – Wind generation at the first point; M – Upper limit of generation growth; l and – coefficients, determining the curve shape.

Variable upper limit:

|  |  |
| --- | --- |
| Y | (13) |

Where *Y(t)* – wind generation at period t; *Xmin* – Wind generation at first point; *M(t)* – the total electricity production in period *t*; *k* – the achievable wind energy generation share; *l* and – coefficients, determining the curve shape.

Variable upper limit considering variable costs:

|  |  |
| --- | --- |
| Y | (14) |

Where Y(t) – wind generation at period t; Xmin – Wind generation at first point; M(t-1) = the total electricity generation in the previous year; R – the price curve coefficient; ct-1 – costs per 1 KWh in the previous year; *l* and – coefficients, determining the curve shape.

1.4 THE RESEARCH STEPS.

The research consists of two steps. The first step serves to provide the consistency check on the models. The equation parameters were evaluated with the OLS criteria using the Gradient Descent optimization method on data from the 1997-2015 period. Then the prognosis for the 2016-2020 period was calculated, and the prognosis consistency according to accurate data was evaluated. The second step evaluates wind energy development by 2050. The model parameters were assessed with the OLS criteria using the Gradient Descent Optimization method on data from the 1997-2020 period. Then the prognoses for the 2020-2050 period was calculated, assuming total electricity generation trends and decreasing wind energy LCOE costs.

**2. RESULTS**

The results are represented with summary tables. The corresponding calculation results and graphs are described in Appendixes D and E. All models fit perfectly to existing data what makes impossible to select “the best one”.

2.1 Model consistency check.

*Table 1. Models consistency check - 2020 WE production model vs. fact (TWh).*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Europe** | **North**  **America** | **South&Central**  **America** | **Asia Pacific**  **region** | **World**  **Total** |
| **WE generation by 2020** | **510.1** | **396.7** | **85.4** | **572** | **1591.2** |
| The “Logistic Growth” Model | | | | | |
| Basic equation | 439 | 261 | 346 | 294 | 1175.3 |
| Variable upper limit | 475 | 264 | 276 | 340 | 1243.5 |
| Variable upper limit considering costs | 495 | 297 | 85 | 388 | 1356.9 |
| The “Bass” Model | | | | | |
| Basic equation | 499 | 384 | 84 | 573 | 1231.8 |
| Variable upper limit | 508 | 384 | 133 | 490 | 1327.8 |
| Variable upper limit considering costs | 544 | 441 | 101 | 582 | 1569.8 |
| The “Gompertz” Model | | | | | |
| Basic equation | 505 | 317 | 217 | 378 | 1508.2 |
| Variable upper limit | 532 | 317 | 119 | 395 | 1510.4 |
| Variable upper limit considering costs | 530 | 335 | 144 | 425 | 1532.3 |

*\*\*\* - 5% deviation from accurate dataset.*

2.2 Results until 2050. The corresponding calculation results and graphs are described in Appendix E.

*Table 2. The WE production (TWh) and share of total electricity production (%) until 2050 (see picture 7 for “Blue trends”) .*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Europe**  2030 / 2040 / 2050  TWh / TWh / TWh  % / % / % | **North**  **America**  2030 / 2040 / 2050  TWh / TWh / TWh  % / % / % | **South&Central**  **America**  2030 / 2040 / 2050  TWh / TWh / TWh  % / % / % | **Asia Pacific**  **Region**  2030 / 2040 / 2050  TWh / TWh / TWh  % / % / % | **World**  **Total**  2030 / 2040 / 2050  TWh / TWh / TWh  % / % / % |
| The total electricity production prognosis | | | | | |
| Linear Model | **4447 / 4717 / 4987** | **5933 / 6322 / 6710** | **1715 / 2019 / 2323** | **16663 / 20742 / 24822** | **33141 / 38968 / 44795** |
| The “Logistic Growth” Model | | | | | |
| Basic equation | 727 / 779 / 787  16.35 / 16.52 / 15.79 | 456 / 462 / 462  7.69 / 7.30 / 6.89 | 95 / 95 / 95  5.58 / 4.74 / 4.12 | 833 / 853 / 853  6.45 / 6.60 / 6.61 | 2349 / 2457 / 2468  7.08 / 6.30 / 5.50 |
| Variable upper limit | 820 / 943 / 1010  18.45 / 19.99 / 20.25 | 492 / 530 / 563  8.30 / 8.39 / 8.40 | 120 / 141 / 163  6.99 / 7.01 / 7.02 | 941 / 1199 / 1441  5.65 / 5.78 / 5.80 | 2604 / 3193 / 3692  7.9 / 8.2 / 8.3 |
| Variable upper limit with costs | 915 / 1193 / 1384  20.59 / 25.30 / 27.75 | 587 / 737 / 860  9.90 / 11.67 / 12.81 | 149 / 207 / 263  8.73 / 10.28 / 11.33 | 1117 / 1667 / 2207  6.70 / 8.03 / 8.89 | 3008 / 4282 / 5436  9.07 / 10.99 / 12.13 |
| The “Bass” Model | | | | | |
| Basic equation | 834 / 944 / 964  18.76 / 20.01 / 19.34 | 473 / 479 / 479  7.98 / 7.57 / 7.14 | 93 / 93 / 93  5.43 / 4.62 / 4.01 | 768 / 774 / 774  5.95 / 5.99 / 5.99 | 2328 / 2402 / 2406  7.02 / 6.16 / 5.37 |
| Variable upper limit | 891 / 1093 / 1193  20.03 / 23.18 / 23.92 | 509 / 551 / 586  8.59 / 8.72 / 8.74 | 122 / 145 /167  7.13 / 7.17 / 7.20 | 1004 / 1282 / 1552  6.02 / 6.18 / 6.25 | 2617 / 3197 / 3714  7.89 / 8.20 / 8.29 |
| Variable upper limit with costs | 930 / 1270 / 1513  20.91 / 26.92 / 30.35 | 636 / 823 / 975  10.72 / 13.02 / 14.53 | 150 / 211 / 269  8.78 / 10.46 / 11.60 | 1204 / 1842 / 2485  7.22 / 8.88 / 10.01 | 2920 / 4206 / 5437  8.81 / 10.79 / 12.13 |
| The “Gompertz” Model | | | | | |
| Basic equation | 964 / 1401 / 1732  21.68 / 29.69 / 34.74 | 585 / 667 / 695  9.86 / 10.56 / 10.36 | 121 / 124 / 124  7.01 / 6.15 / 5.35 | 1293 / 1787 / 2037  7.75 / 8.61 / 8.2 | 3454 / 5127 / 6270  10.42 / 13.15 / 13.99 |
| Variable upper limit | 1057 / 1639 / 2157  23.78 / 34.75 / 43.25 | 620 / 743 / 817  10.46 / 11.75 / 12.17 | 148 / 179 / 206  8.66 / 8.86 / 8.89 | 1202 / 1759 / 2222  7.21 / 8.48 / 8.95 | 3362 / 5113 / 6601  10.14 / 13.12 / 14.73 |
| Variable upper limit with costs | 1063 / 1640 / 2137  23.90 / 34.76 / 42.86 | 662 / 862 / 1012  11.16 / 13.64 / 15.09 | 172 / 240 / 304  10.03 / 11.90 / 13.09 | 1271 / 2008 / 2701  7.63 / 9.68 / 10.88 | 3504 / 5550 / 7392  10.57 / 14.24 / 16.50 |
| **“Summary”** | | | | | |
| **Min** | **727 / 779 / 787**  **16.35 / 16.52 / 15.79** | **456 / 462 / 462**  **7.69 / 7.30 / 6.89** | **93 / 93 / 93**  **5.43 / 4.62 / 4.01** | **768 / 774 / 774**  **5.95 / 5.99 / 5.99** | **2328 / 2402 / 2406**  **7.02 / 6.16 / 5.37** |
| **Max** | **1063 / 1640 / 2157**  **23.90 / 34.76 / 43.25** | **662 / 862 / 1012**  **11.16 / 13.64 / 15.09** | **172 / 240 / 304**  **10.03 / 11.90 / 13.09** | **1293 / 2008 / 2701**  **7.75 / 9.68 / 10.88** | **3504 / 5550 / 7392**  **10.57 / 14.24 / 16.50** |
| **Avg** | **911 / 1211 / 1430**  **20.48 / 25.67 / 28.67** | **557 / 650 / 716**  **9.38 / 10.28 / 10.67** | **149 / 159 / 187**  **8.68 / 7.87 / 8.04** | **1070 / 1463 / 1808**  **6.42 / 7.05 / 7.28** | **2905 / 3947 / 4824**  **8.76 / 10.12 / 10.76** |

**Picture 7. WE generation trends (TWh) obtained from different models considering linear growth electricity generation trends**

**and decreasing costs (see appendixes B and C).**

**3. DISCUSSION**

All models could be attuned to completely correspond to the real data (see Appendix E) from 1995 to 2020, which makes the choice of an appropriate model to make evaluations almost impossible. The consistency analyses (see Table 1 and Appendix D) show the adequacy of different models for different regions. Europe has mostly reliable trends, while South America has a mostly optimistic prognosis and North America as well as the World total is mostly underestimated. Nevertheless, we obtained at least two models with high accuracy (the mistake is less than five percent of the target value) for each region. That is quite good predicting ability considering the almost double growth of WE production during the 2015-2020 period.

The consistency check results (see Table 1 and Appendix D) allow the trend analysis (see Table 2 and Appendix E) to pretend to represent the borders for WE development trends. The pessimistic trend is quite a “scary” cause of the diminishing share of WE in total electricity production considering its linear growth (see Appendix B) by 2050, while the optimistic evaluation and averaged trends predict the evolution of WE share.

The mostly interesting is the fact, that all evaluated models perfectly fit the historical data. Thus, we could not evaluate the model applicability on the parameters determination step. The consistency check stage show the Bass model the mostly accurate for most regions within the 5 years period. As for the “long-distance” evaluation, mostly pessimistic prognoses were made with the “Logistic growth” model, while the mostly optimistic trends are represented within the “Gompertz” model.

Another interesting fact is that Bass model shows significant part of “innovators” only for Europe, while other regions are driven by “imitators” only. Considering the moderate growth of electricity generation in Europe and North America during 1995-2020 period, compared to double growth in South America and triple growth in Asia Pacific region we could guess that while Europe provides the progress by replacing the traditional sources within the “green” ones, other regions just try to cover its growing energetic appetite from all the possible sources.

**4. CONCLUSION**

The prognoses of 35% and more world total electricity generation from wind by 2050 are too optimistic, according to the “Diffusion of innovation” numeric models we had evaluated (see Table 2, appendix E). Only Europe could reach the claimed amount of WE production within the borders of the evaluated models. The world`s total wind energy production lies in the 5.3% - 16.5% interval which mostly corresponds to other prognoses.

APPENDIX A. WE SHARE LIMIT OF TOTAL ELECTRICITY GENERATION DEPENDING ON COSTS EXAMPLE.

APPENDIX B. ELECTRICITY GENERATION LINEAR TRENDS.

**World**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Regeression*** | |  |  |  |  |  |  |  |
| **R** | **0,997287246** |  |  |  |  |  |  |  |
| **R2** | **0,994581851** |  |  |  |  |  |  |  |
| **Normal R2** | **0,994356095** |  |  |  |  |  |  |  |
| **St.err.** | **335,7407901** |  |  |  |  |  |  |  |
| **Obs.** | **26** |  |  |  |  |  |  |  |
| **Dispersion** |  |  |  |  |  |  |  |  |
|  | ***df*** | ***SS*** | ***MS*** | ***F*** | ***Sig. F*** |  |  |  |
| **Regression** | **1** | **496602650,8** | **496602650,8** | **4405,556924** | **1,03422E-28** |  |  |  |
| **Residiual** | **24** | **2705325,075** | **112721,8781** |  |  |  |  |  |
| **Summary** | **25** | **499307975,9** |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  | ***Coef.*** | ***St.err.*** | ***t-value*** | ***P-Value*** | ***Lowest 95%*** | ***Upper 95%*** |
| **Y** | **-1149771,31** | **17624,41683** | **-65,2374102** | **1,56223E-28** | **-1186146,318** | **-1113396,301** |
| **X 1** | **582,7155121** | **8,779224822** | **66,37436948** | **1,03422E-28** | **564,5960826** | **600,8349416** |

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Generation** | **Regression** | **Year** | **Generation** | **Regression** | **Year** | **Model** | **Year** | **Model** | **Year** | **Model** |
| 1995 | 13375,24396 | 12746,1367 | 2009 | 20264,89106 | 20904,15387 | 2021 | 27896,74002 | 2035 | 36054,75719 | 2049 | 44212,77436 |
| 1996 | 13789,24953 | 13328,85221 | 2010 | 21570,68886 | 21486,86938 | 2022 | 28479,45553 | 2036 | 36637,4727 | 2050 | 44795,48987 |
| 1997 | 14120,51713 | 13911,56773 | 2011 | 22256,99524 | 22069,5849 | 2023 | 29062,17104 | 2037 | 37220,18821 |  |  |
| 1998 | 14502,91924 | 14494,28324 | 2012 | 22806,27648 | 22652,30041 | 2024 | 29644,88655 | 2038 | 37802,90372 |  |  |
| 1999 | 14917,76376 | 15076,99875 | 2013 | 23435,23821 | 23235,01592 | 2025 | 30227,60207 | 2039 | 38385,61923 |  |  |
| 2000 | 15555,54829 | 15659,71426 | 2014 | 24031,70705 | 23817,73143 | 2026 | 30810,31758 | 2040 | 38968,33475 |  |  |
| 2001 | 15788,86061 | 16242,42977 | 2015 | 24270,50094 | 24400,44694 | 2027 | 31393,03309 | 2041 | 39551,05026 |  |  |
| 2002 | 16345,48432 | 16825,14529 | 2016 | 24915,18711 | 24983,16246 | 2028 | 31975,7486 | 2042 | 40133,76577 |  |  |
| 2003 | 16924,01841 | 17407,8608 | 2017 | 25623,89225 | 25565,87797 | 2029 | 32558,46411 | 2043 | 40716,48128 |  |  |
| 2004 | 17726,74751 | 17990,57631 | 2018 | 26659,13624 | 26148,59348 | 2030 | 33141,17963 | 2044 | 41299,1968 |  |  |
| 2005 | 18454,11881 | 18573,29182 | 2019 | 27000,95085 | 26731,30899 | 2031 | 33723,89514 | 2045 | 41881,91231 |  |  |
| 2006 | 19155,29112 | 19156,00734 | 2020 | 26823,24835 | 27314,0245 | 2032 | 34306,61065 | 2046 | 42464,62782 |  |  |
| 2007 | 20045,983 | 19738,72285 |  |  |  | 2033 | 34889,32616 | 2047 | 43047,34333 |  |  |
| 2008 | 20421,63735 | 20321,43836 |  |  |  | 2034 | 35472,04167 | 2048 | 43630,05884 |  |  |

**Europe**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Regeression*** | |  |  |  |  |  |  |  |
| **R** | **0,815530521** |  |  |  |  |  |  |  |
| **R2** | **0,665090031** |  |  |  |  |  |  |  |
| **Normal R2** | **0,651135449** |  |  |  |  |  |  |  |
| **St.err.** | **149,5637939** |  |  |  |  |  |  |  |
| **Obs.** | **26** |  |  |  |  |  |  |  |
| **Dispersion** |  |  |  |  |  |  |  |  |
|  | ***df*** | ***SS*** | ***MS*** | ***F*** | ***Sig. F*** |  |  |  |
| **Regression** | **1** | **1066145,678** | **1066145,678** | **47,66104987** | **3,86316E-07** |  |  |  |
| **Residiual** | **24** | **536863,8824** | **22369,32843** |  |  |  |  |  |
| **Summary** | **25** | **1603009,56** |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  | ***Coef.*** | ***St.err.*** | ***t-value*** | ***P-Value*** | ***Lowest 95%*** | ***Upper 95%*** |
| **Y** | **-50361,69763** | **7851,219521** | **-6,414506371** | **1,24079E-06** | **-66565,81831** | **-34157,57696** |
| **X 1** | **26,999787** | **3,910916428** | **6,903698275** | **3,86316E-07** | **18,92805221** | **35,07152179** |

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Generation** | **Regression** | **Year** | **Generation** | **Regression** | **Year** | **Model** | **Year** | **Model** | **Year** | **Model** |
| 1995 | 3279,587267 | 3502,877424 | 2009 | 3894,691692 | 3880,874442 | 2021 | 4204,871886 | 2035 | 4582,868904 | 2049 | 4960,865922 |
| 1996 | 3353,864548 | 3529,877211 | 2010 | 4065,763115 | 3907,874229 | 2022 | 4231,871673 | 2036 | 4609,868691 | 2050 | 4987,865709 |
| 1997 | 3389,195436 | 3556,876998 | 2011 | 4019,422767 | 3934,874016 | 2023 | 4258,87146 | 2037 | 4636,868478 |  |  |
| 1998 | 3466,419163 | 3583,876785 | 2012 | 4053,115304 | 3961,873803 | 2024 | 4285,871247 | 2038 | 4663,868265 |  |  |
| 1999 | 3509,426879 | 3610,876572 | 2013 | 4022,201398 | 3988,87359 | 2025 | 4312,871034 | 2039 | 4690,868052 |  |  |
| 2000 | 3620,282803 | 3637,876359 | 2014 | 3939,246815 | 4015,873377 | 2026 | 4339,870821 | 2040 | 4717,867839 |  |  |
| 2001 | 3685,098394 | 3664,876146 | 2015 | 3982,659249 | 4042,873164 | 2027 | 4366,870608 | 2041 | 4744,867626 |  |  |
| 2002 | 3718,568773 | 3691,875933 | 2016 | 4021,409945 | 4069,872951 | 2028 | 4393,870395 | 2042 | 4771,867413 |  |  |
| 2003 | 3811,589001 | 3718,87572 | 2017 | 4061,257295 | 4096,872738 | 2029 | 4420,870182 | 2043 | 4798,8672 |  |  |
| 2004 | 3898,059649 | 3745,875507 | 2018 | 4065,532501 | 4123,872525 | 2030 | 4447,869969 | 2044 | 4825,866987 |  |  |
| 2005 | 3959,873797 | 3772,875294 | 2019 | 3992,114841 | 4150,872312 | 2031 | 4474,869756 | 2045 | 4852,866774 |  |  |
| 2006 | 4015,794421 | 3799,875081 | 2020 | 3871,310532 | 4177,872099 | 2032 | 4501,869543 | 2046 | 4879,866561 |  |  |
| 2007 | 4064,6933 | 3826,874868 |  |  |  | 2033 | 4528,86933 | 2047 | 4906,866348 |  |  |
| 2008 | 4088,564918 | 3853,874655 |  |  |  | 2034 | 4555,869117 | 2048 | 4933,866135 |  |  |

**North America**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Regeression*** | |  |  |  |  |  |  |  |
| **R** | **0,885697493** |  |  |  |  |  |  |  |
| **R2** | **0,784460049** |  |  |  |  |  |  |  |
| **Normal R2** | **0,775479218** |  |  |  |  |  |  |  |
| **St.err.** | **158,9922409** |  |  |  |  |  |  |  |
| **Obs.** | **26** |  |  |  |  |  |  |  |
| **Dispersion** |  |  |  |  |  |  |  |  |
|  | ***df*** | ***SS*** | ***MS*** | ***F*** | ***Sig. F*** |  |  |  |
| **Regression** | **1** | **2208036,025** | **2208036,025** | **87,34826718** | **1,81082E-09** |  |  |  |
| **Residiual** | **24** | **606684,7839** | **25278,53266** |  |  |  |  |  |
| **Summary** | **25** | **2814720,809** |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  | ***Coef.*** | ***St.err.*** | ***t-value*** | ***P-Value*** | ***Lowest 95%*** | ***Upper 95%*** |
| **Y** | **-72943,36622** | **8346,157536** | **-8,7397543** | **6,36986E-09** | **-90168,98875** | **-55717,74368** |
| **X 1** | **38,85573603** | **4,157459173** | **9,346029488** | **1,81082E-09** | **30,27516202** | **47,43631004** |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Generation** | **Regression** | **Year** | **Generation** | **Regression** | **Year** | **Model** | **Year** | **Model** | **Year** | **Model** |
| 1995 | 4275,556188 | 4573,827158 | 2009 | 5088,123518 | 5117,807462 | 2021 | 5584,076295 | 2035 | 6128,056599 | 2049 | 6672,036903 |
| 1996 | 4391,598772 | 4612,682894 | 2010 | 5276,82968 | 5156,663198 | 2022 | 5622,932031 | 2036 | 6166,912335 | 2050 | 6710,892639 |
| 1997 | 4455,467215 | 4651,53863 | 2011 | 5293,80201 | 5195,518934 | 2023 | 5661,787767 | 2037 | 6205,768071 |  |  |
| 1998 | 4598,858828 | 4690,394366 | 2012 | 5243,51448 | 5234,37467 | 2024 | 5700,643503 | 2038 | 6244,623807 |  |  |
| 1999 | 4703,849938 | 4729,250102 | 2013 | 5283,091761 | 5273,230406 | 2025 | 5739,499239 | 2039 | 6283,479543 |  |  |
| 2000 | 4859,697274 | 4768,105838 | 2014 | 5314,194586 | 5312,086142 | 2026 | 5778,354975 | 2040 | 6322,335279 |  |  |
| 2001 | 4782,434635 | 4806,961574 | 2015 | 5318,368443 | 5350,941878 | 2027 | 5817,210711 | 2041 | 6361,191015 |  |  |
| 2002 | 4927,289764 | 4845,81731 | 2016 | 5331,097285 | 5389,797614 | 2028 | 5856,066447 | 2042 | 6400,046751 |  |  |
| 2003 | 4951,151555 | 4884,673046 | 2017 | 5287,716919 | 5428,65335 | 2029 | 5894,922183 | 2043 | 6438,902487 |  |  |
| 2004 | 5065,58895 | 4923,528782 | 2018 | 5452,457105 | 5467,509086 | 2030 | 5933,777919 | 2044 | 6477,758223 |  |  |
| 2005 | 5194,997787 | 4962,384518 | 2019 | 5382,419781 | 5506,364822 | 2031 | 5972,633655 | 2045 | 6516,613959 |  |  |
| 2006 | 5199,199043 | 5001,240254 | 2020 | 5243,638325 | 5545,220559 | 2032 | 6011,489391 | 2046 | 6555,469695 |  |  |
| 2007 | 5332,170513 | 5040,09599 |  |  |  | 2033 | 6050,345127 | 2047 | 6594,325431 |  |  |
| 2008 | 5294,50596 | 5078,951726 |  |  |  | 2034 | 6089,200863 | 2048 | 6633,181167 |  |  |

**South and Central America**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Regeression*** | |  |  |  |  |  |  |  |
| **R** | **0,984874915** |  |  |  |  |  |  |  |
| **R2** | **0,969978599** |  |  |  |  |  |  |  |
| **Normal R2** | **0,968727707** |  |  |  |  |  |  |  |
| **St.err.** | **41,71260947** |  |  |  |  |  |  |  |
| **Obs.** | **26** |  |  |  |  |  |  |  |
| **Dispersion** |  |  |  |  |  |  |  |  |
|  | ***df*** | ***SS*** | ***MS*** | ***F*** | ***Sig. F*** |  |  |  |
| **Regression** | **1** | **1349202,546** | **1349202,546** | **775,4297038** | **8,76167E-20** |  |  |  |
| **Residiual** | **24** | **41758,60294** | **1739,941789** |  |  |  |  |  |
| **Summary** | **25** | **1390961,149** |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  | ***Coef.*** | ***St.err.*** | ***t-value*** | ***P-Value*** | ***Lowest 95%*** | ***Upper 95%*** |
| **Y** | **-59941,76687** | **2189,666665** | **-27,37483646** | **1,30446E-19** | **-64461,01675** | **-55422,51699** |
| **X 1** | **30,37320621** | **1,090735434** | **27,84653845** | **8,76167E-20** | **28,12203892** | **32,6243735** |

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Generation** | **Regression** | **Year** | **Generation** | **Regression** | **Year** | **Model** | **Year** | **Model** | **Year** | **Model** |
| 1995 | 646,3818316 | 652,7795216 | 2009 | 1082,959839 | 1078,004409 | 2021 | 1442,482883 | 2035 | 1867,70777 | 2049 | 2292,932657 |
| 1996 | 678,8031705 | 683,1527278 | 2010 | 1140,474922 | 1108,377615 | 2022 | 1472,856089 | 2036 | 1898,080976 | 2050 | 2323,305863 |
| 1997 | 717,648455 | 713,525934 | 2011 | 1181,093878 | 1138,750821 | 2023 | 1503,229295 | 2037 | 1928,454182 |  |  |
| 1998 | 748,8858751 | 743,8991402 | 2012 | 1231,422072 | 1169,124027 | 2024 | 1533,602502 | 2038 | 1958,827389 |  |  |
| 1999 | 772,4345023 | 774,2723465 | 2013 | 1267,608313 | 1199,497233 | 2025 | 1563,975708 | 2039 | 1989,200595 |  |  |
| 2000 | 808,710595 | 804,6455527 | 2014 | 1287,259577 | 1229,87044 | 2026 | 1594,348914 | 2040 | 2019,573801 |  |  |
| 2001 | 796,3839728 | 835,0187589 | 2015 | 1296,605291 | 1260,243646 | 2027 | 1624,72212 | 2041 | 2049,947007 |  |  |
| 2002 | 821,2902116 | 865,3919651 | 2016 | 1305,591533 | 1290,616852 | 2028 | 1655,095327 | 2042 | 2080,320213 |  |  |
| 2003 | 861,1566269 | 895,7651713 | 2017 | 1306,794565 | 1320,990058 | 2029 | 1685,468533 | 2043 | 2110,69342 |  |  |
| 2004 | 901,8812618 | 926,1383775 | 2018 | 1330,890601 | 1351,363264 | 2030 | 1715,841739 | 2044 | 6477,758223 |  |  |
| 2005 | 943,2056773 | 956,5115837 | 2019 | 1339,01424 | 1381,736471 | 2031 | 1746,214945 | 2045 | 6516,613959 |  |  |
| 2006 | 988,3803506 | 986,8847899 | 2020 | 1282,821203 | 1412,109677 | 2032 | 1776,588151 | 2046 | 6555,469695 |  |  |
| 2007 | 1034,177932 | 1017,257996 |  |  |  | 2033 | 1806,961358 | 2047 | 6594,325431 |  |  |
| 2008 | 1071,683083 | 1047,631202 |  |  |  | 2034 | 1837,334564 | 2048 | 6633,181167 |  |  |

**Asia Pacific**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Regeression*** | |  |  |  |  |  |  |  |
| **R** | **0,990349656** |  |  |  |  |  |  |  |
| **R2** | **0,980792441** |  |  |  |  |  |  |  |
| **Normal R2** | **0,979992126** |  |  |  |  |  |  |  |
| **St.err.** | **445,6760252** |  |  |  |  |  |  |  |
| **Obs.** | **26** |  |  |  |  |  |  |  |
| **Dispersion** |  |  |  |  |  |  |  |  |
|  | ***df*** | ***SS*** | ***MS*** | ***F*** | ***Sig. F*** |  |  |  |
| **Regression** | **1** | **243419137,9** | **243419137,9** | **1225,508071** | **4,10075E-22** |  |  |  |
| **Residiual** | **24** | **4767050,867** | **198627,1195** |  |  |  |  |  |
| **Summary** | **25** | **248186188,8** |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  | ***Coef.*** | ***St.err.*** | ***t-value*** | ***P-Value*** | ***Lowest 95%*** | ***Upper 95%*** |
| **Y** | **-811518,1694** | **23395,37009** | **-34,68712683** | **5,09134E-22** | **-859803,8401** | **-763232,4987** |
| **X 1** | **407,9711218** | **11,65390128** | **35,0072574** | **4,10075E-22** | **383,9186517** | **432,0235918** |

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Generation** | **Regression** | **Year** | **Generation** | **Regression** | **Year** | **Model** | **Year** | **Model** | **Year** | **Model** |
| 1995 | 3395,296509 | 2384,218499 | 2009 | 7537,49367 | 8095,814204 | 2021 | 12991,46766 | 2035 | 18703,06337 | 2049 | 24414,65907 |
| 1996 | 3571,36384 | 2792,189621 | 2010 | 8257,695762 | 8503,785326 | 2022 | 13399,43879 | 2036 | 19111,03449 | 2050 | 24822,6302 |
| 1997 | 3742,362872 | 3200,160743 | 2011 | 8875,060397 | 8911,756447 | 2023 | 13807,40991 | 2037 | 19519,00561 |  |  |
| 1998 | 3849,126094 | 3608,131864 | 2012 | 9278,135735 | 9319,727569 | 2024 | 14215,38103 | 2038 | 19926,97673 |  |  |
| 1999 | 4039,02947 | 4016,102986 | 2013 | 9812,30959 | 9727,698691 | 2025 | 14623,35215 | 2039 | 20334,94786 |  |  |
| 2000 | 4285,699691 | 4424,074108 | 2014 | 10333,718 | 10135,66981 | 2026 | 15031,32327 | 2040 | 20742,91898 |  |  |
| 2001 | 4477,992791 | 4832,04523 | 2015 | 10433,85199 | 10543,64093 | 2027 | 15439,2944 | 2041 | 21150,8901 |  |  |
| 2002 | 4762,239984 | 5240,016351 | 2016 | 10947,57602 | 10951,61206 | 2028 | 15847,26552 | 2042 | 21558,86122 |  |  |
| 2003 | 5098,70706 | 5647,987473 | 2017 | 11569,79978 | 11359,58318 | 2029 | 16255,23664 | 2043 | 21966,83234 |  |  |
| 2004 | 5567,612705 | 6055,958595 | 2018 | 12339,29722 | 11767,5543 | 2030 | 16663,20776 | 2044 | 22374,80347 |  |  |
| 2005 | 5971,267224 | 6463,929717 | 2019 | 12741,57102 | 12175,52542 | 2031 | 17071,17888 | 2045 | 22782,77459 |  |  |
| 2006 | 6456,820579 | 6871,900839 | 2020 | 12919,33414 | 12583,49654 | 2032 | 17479,15 | 2046 | 23190,74571 |  |  |
| 2007 | 7014,726248 | 7279,87196 |  |  |  | 2033 | 17887,12113 | 2047 | 23598,71683 |  |  |
| 2008 | 7302,207162 | 7687,843082 |  |  |  | 2034 | 18295,09225 | 2048 | 24006,68795 |  |  |

APPENDIX C. COSTS EVALUATION MODEL.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Regeression*** | |  |  |  |  |  |  |  |
| **R** | **0,98489375** |  |  |  |  |  |  |  |
| **R2** | **0,970015699** |  |  |  |  |  |  |  |
| **Normal R2** | **0,968766353** |  |  |  |  |  |  |  |
| **St.err.** | **0,006703051** |  |  |  |  |  |  |  |
| **Obs.** | **26** |  |  |  |  |  |  |  |
| **Dispersion** |  |  |  |  |  |  |  |  |
|  | ***df*** | ***SS*** | ***MS*** | ***F*** | ***Sig. F*** |  |  |  |
| **Regression** | **1** | **0,0348852** | **0,0348852** | **776,4188541** | **8,63246E-20** |  |  |  |
| **Residiual** | **24** | **0,0010783** | **4,4931E-05** |  |  |  |  |  |
| **Summary** | **25** | **0,0359635** |  |  |  |  |  |  |
|  | **1** | **0,0348852** | **0,0348852** | **776,4188541** | **8,63246E-20** |  |  |  |
|  | ***Coef.*** | ***St.err.*** | ***t-value*** | ***P-Value*** | ***Lowest 95%*** | ***Upper 95%*** |
| **Y** | **-0,00536851** | **0,0040818** | **-1,3152349** | **0,20085906** | **-0,013792903** | **0,003055886** |
| **X 1** | **1,059445879** | **0,0380216** | **27,8642935** | **8,63246E-20** | **0,98097309** | **1,137918668** |

**K=0.145261**

**L=0.065398**

**M=0.029549**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Costs** | **Model** | **Year** | **Costs** | **Model** | **Year** | **Model** | **Year** | **Model** | **Year** | **Model** |
| 1995 | 0,196 | 0,174889 | 2009 | 0,087 | 0,087598 | 2021 | 0,05607605 | 2035 | 0,040167298 | 2049 | 0,033799262 |
| 1996 | 0,178 | 0,16565 | 2010 | 0,086 | 0,083925 | 2022 | 0,054396724 | 2036 | 0,039495089 | 2050 | 0,033530187 |
| 1997 | 0,157 | 0,157 | 2011 | 0,083 | 0,080486 | 2023 | 0,052823709 | 2037 | 0,038865435 |  |  |
| 1998 | 0,139 | 0,148901 | 2012 | 0,083 | 0,077267 | 2024 | 0,051350275 | 2038 | 0,038275641 |  |  |
| 1999 | 0,134 | 0,141319 | 2013 | 0,082 | 0,074253 | 2025 | 0,049970118 | 2039 | 0,037723185 |  |  |
| 2000 | 0,142 | 0,134221 | 2014 | 0,076 | 0,071431 | 2026 | 0,048677334 | 2040 | 0,037205702 |  |  |
| 2001 | 0,126 | 0,127575 | 2015 | 0,069 | 0,068789 | 2027 | 0,04746639 | 2041 | 0,03672098 |  |  |
| 2002 | 0,119 | 0,121353 | 2016 | 0,066 | 0,066316 | 2028 | 0,046332105 | 2042 | 0,036266943 |  |  |
| 2003 | 0,106 | 0,115527 | 2017 | 0,064 | 0,064 | 2029 | 0,045269628 | 2043 | 0,035841649 |  |  |
| 2004 | 0,111 | 0,110074 | 2018 | 0,058 | 0,061832 | 2030 | 0,044274412 | 2044 | 0,035443278 |  |  |
| 2005 | 0,104 | 0,104967 | 2019 | 0,053 | 0,059802 | 2031 | 0,043342198 | 2045 | 0,035070127 |  |  |
| 2006 | 0,105 | 0,100187 | 2020 | 0,05 | 0,057869 | 2032 | 0,042468999 | 2046 | 0,034720599 |  |  |
| 2007 | 0,098 | 0,095711 |  |  |  | 2033 | 0,041651079 | 2047 | 0,034393198 |  |  |
| 2008 | 0,088 | 0,091521 |  |  |  | 2034 | 0,040884938 | 2048 | 0,034086523 |  |  |

APPENDIX D. THE MODELS CONSISTENCY CHECK.

The “Bass” model – original equation

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **p** | **q** | **m** |
| World | 0 | 0,302781 | 1394,232 |
| Europe | 0,002695456 | 0,185993 | 797,2492 |
| North America | 0 | 0,272163 | 479,3177 |
| South, Central America | 0 | 0,534315 | 93,31387 |
| Asia Pacific | 1,63683E-06 | 0,334964 | 774,1022 |

The “Bass” model – variable upper limit

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **p** | **q** | **k** |
| World | 0 | 0,308276089 | 0,059196566 |
| Europe | 0,003028892 | 0,177879763 | 0,217400977 |
| North America | 0 | 0,273171149 | 0,089366412 |
| South, Central America | 1,68007E-07 | 0,514387768 | 0,163180329 |
| Asia Pacific | 0 | 0,354638269 | 0,049283975 |

The “Bass” model – variable upper limit considering costs

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **p** | **q** | **R** |
| World | 0 | 0,317073032 | 0,004915116 |
| Europe | 0,005130792 | 0,161493593 | 0,025482218 |
| North America | 0 | 0,278624172 | 0,007651171 |
| South, Central America | 0 | 0,525062035 | 0,006203917 |
| Asia Pacific | 0 | 0,361021644 | 0,004090776 |

The “Logistic Growth” model – original equation

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **l** | **a** | **M** |
| World | 0,3030346 | 18,47168948 | 1328,489096 |
| Europe | 0,228200173 | 18,9609983 | 544,9412295 |
| North America | 0,423394538 | 16,14200836 | 264,5654892 |
| South, Central America | 0,49252378 | 30,87711072 | 6602,242898 |
| Asia Pacific | 0,485603536 | 17,05944876 | 299,6807747 |

The “Logistic Growth” model – variable upper limit

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **l** | **a** | **k** |
| World | 0,282654868 | 17,65622106 | 0,051490867 |
| Europe | 0,208153283 | 20,74438621 | 0,167011708 |
| North America | 0,424613105 | 16,05988732 | 0,049579726 |
| South, Central America | 0,471586229 | 27,85899996 | 11 |
| Asia Pacific | 0,472222248 | 15,95387736 | 0,027027013 |

The “Logistic Growth” model – variable upper limit considering costs

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **k** | **a** | **R** |
| World | 0,258165921 | 16,02724753 | 0,003471514 |
| Europe | 0,176516031 | 19,23666818 | 0,012058564 |
| North America | 0,427318168 | 14,95002112 | 0,003512937 |
| South, Central America | 0,575249366 | 20,62882063 | 0,004431881 |
| Asia Pacific | 0,485484377 | 14,96783275 | 0,001889112 |

The “Gompertz” model – original equation

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **k** | **a** | **R** |
| World | 0,258165921 | 16,02724753 | 0,003471514 |
| Europe | 0,176516031 | 19,23666818 | 0,012058564 |
| North America | 0,427318168 | 14,95002112 | 0,003512937 |
| South, Central America | 0,575249366 | 20,62882063 | 0,004431881 |
| Asia Pacific | 0,485484377 | 14,96783275 | 0,001889112 |

The “Gompertz” model – variable upper limit

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **k** | **a** | **R** |
| World | 0,258165921 | 16,02724753 | 0,003471514 |
| Europe | 0,176516031 | 19,23666818 | 0,012058564 |
| North America | 0,427318168 | 14,95002112 | 0,003512937 |
| South, Central America | 0,575249366 | 20,62882063 | 0,004431881 |
| Asia Pacific | 0,485484377 | 14,96783275 | 0,001889112 |

The “Gompertz” model – variable upper limit considering costs.

|  |  |  |  |
| --- | --- | --- | --- |
|  | MODEL PARAMETERS | | |
|  | **k** | **a** | **R** |
| World | 0,258165921 | 16,02724753 | 0,003471514 |
| Europe | 0,176516031 | 19,23666818 | 0,012058564 |
| North America | 0,427318168 | 14,95002112 | 0,003512937 |
| South, Central America | 0,575249366 | 20,62882063 | 0,004431881 |
| Asia Pacific | 0,485484377 | 14,96783275 | 0,001889112 |

APPENDIX E. RESULTS.

WORLD TOTAL

The Original Bass model

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 0,0005727 | 0,249517965 | 2407,09678 |

The Bass model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| p | q | k |
| 0,000824762 | 0,263758475 | 0,087473446 |

The Bass model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| p | q | R |
| 0 | 0,31555009 | 0,00508028 |

The Logistic growth model

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,241864265 | 22,71470708 | 2460,900909 |

The logistic growth model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,226659184 | 21,37602152 | 0,083369463 |

The logistic growth model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,209291561 | 18,82355251 | 0,00478394 |

The Gompertz model

|  |  |  |
| --- | --- | --- |
| B | C | M |
| 2,14963558 | 0,067589212 | 7713,561514 |

The Gompertz model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 2,035458035 | 0,080145014 | 0,163708564 |

The Gompertz model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 1,814129935 | 0,092911985 | 0,007160918 |

EUROPE

The Original Bass model

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 0,002690579 | 0,16567796 | 968,8619049 |

The Bass model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 0,003099661 | 0,16096477 | 0,249328963 |

The Bass model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 0,007183347 | 0,174899475 | 0,016539284 |

The Logistic Growth model

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,194725399 | 22,35672529 | 785,1434854 |

The Logistic Growth model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,188302957 | 22,8048091 | 0,20336905 |

The Logistic Growth model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,162526105 | 20,44369454 | 0,013237872 |

The Gompertz Model

|  |  |  |
| --- | --- | --- |
| B | C | M |
| 1,835746925 | 0,056484286 | 2288,977191 |

The Gompertz model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 1,821980723 | 0,055167088 | 0,584556919 |

The Gompertz model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 1,587813773 | 0,058159296 | 0,037789816 |

NORTH AMERICA

The Original Bass model

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 0 | 0,271427279 | 479,2328093 |

The Bass model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| p | q | k |
| 9,16073E-07 | 0,272498875 | 0,089347043 |

The Bass model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| p | Q | R |
| 0 | 0,289221906 | 0,006105098 |

The Logistic Growth model

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,285100766 | 19,78269899 | 459,1809454 |

The Logistic Growth model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,286102973 | 19,55844979 | 0,084039341 |

The Logistic Growth model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,287233686 | 17,38647048 | 0,005032602 |

The Gompertz Model

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 2,426782151 | 0,116526991 | 705,3470822 |

The Gompertz model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 2,451252377 | 0,121143614 | 0,123819749 |

The Gompertz model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 2,495958973 | 0,152201729 | 0,006110959 |

SOUTH AND CENTRAL AMERICA

The Original Bass model

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 0 | 0,534315123 | 93,31386801 |

The Bass model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 0 | 0,532486425 | 0,073950782 |

The Bass model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| p | Q | R |
| 0 | 0,544446404 | 0,004652554 |

The Logistic Growth model

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,563395162 | 21,37481637 | 95,82821158 |

The Logistic Growth model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,560193594 | 21,23745888 | 0,07122644 |

The Logistic Growth model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,575005273 | 20,62944786 | 0,004432595 |

The Gompertz Model

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 5,608006241 | 0,264575712 | 124,514603 |

The Gompertz model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 5,68886466 | 0,271555677 | 0,090121638 |

The Gompertz model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 6,205223794 | 0,309697042 | 0,005226002 |

ASIA PACIFIC

The Original Bass model

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 0 | 0,534315123 | 93,31386801 |

The Bass model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| p | q | m |
| 3,63378E-05 | 0,342227695 | 0,065900424 |

The Bass model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| p | Q | R |
| 0 | 0,364280664 | 0,004088578 |

The Logistic Growth model

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,301578477 | 22,65591552 | 852,9135475 |

The Logistic Growth model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,277807284 | 20,79570835 | 0,058996963 |

The Logistic Growth model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 0,269111712 | 18,80373767 | 0,003394501 |

The Gompertz Model

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 2,568742461 | 0,090816957 | 2224,594236 |

The Gompertz model with variable upper limit considering linear total electricity generation growth trend

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 2,495292812 | 0,113003921 | 0,093224394 |

The Gompertz model with variable upper limit considering linear total electricity generation growth and decreasing costs trends

|  |  |  |
| --- | --- | --- |
| k | Alpha | M |
| 2,497245716 | 0,138255477 | 0,00427608 |

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