Deutsche Gesellschaft für Sonnenenergie e.V.
International Solar Energy Society, German Section

Energieverbrauch und CO_2-Bilanz von Pedelecs

Tomi Engel

Köln - IFMA - 19.09.2008

Electric vehicles

Does the additional use of electricity in LEVs increase the CO_2-Emissions of our Country?

DGS Study: CO_2-Emissions from (PH)EVs

10 Mio. EVs

30 Mio. PHEVs

ISBN 978-3-89963-327-6
erhältlich im DGS-Buchshop
oder beim Verlag Dr. Hut

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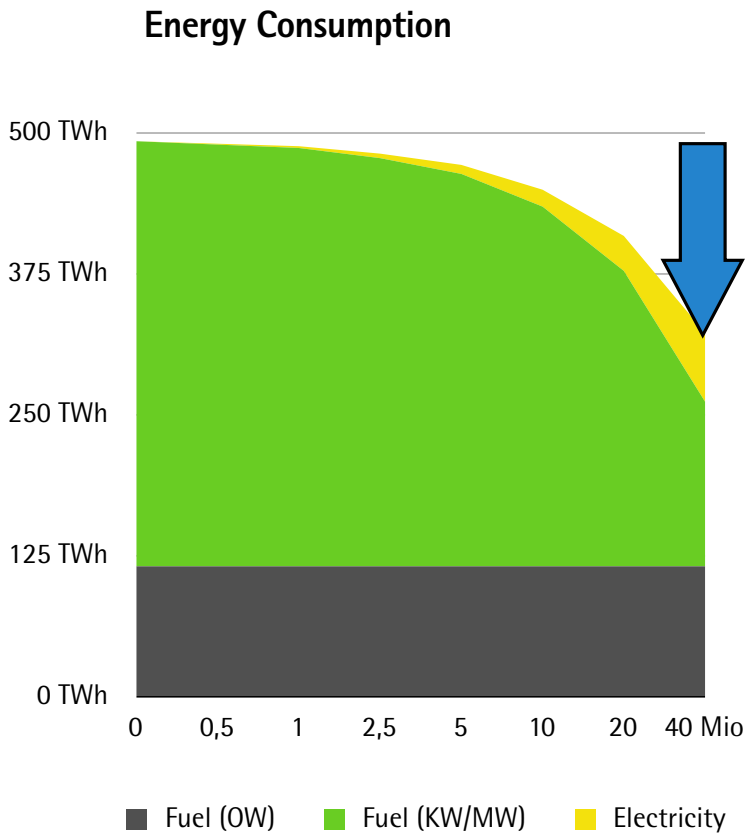

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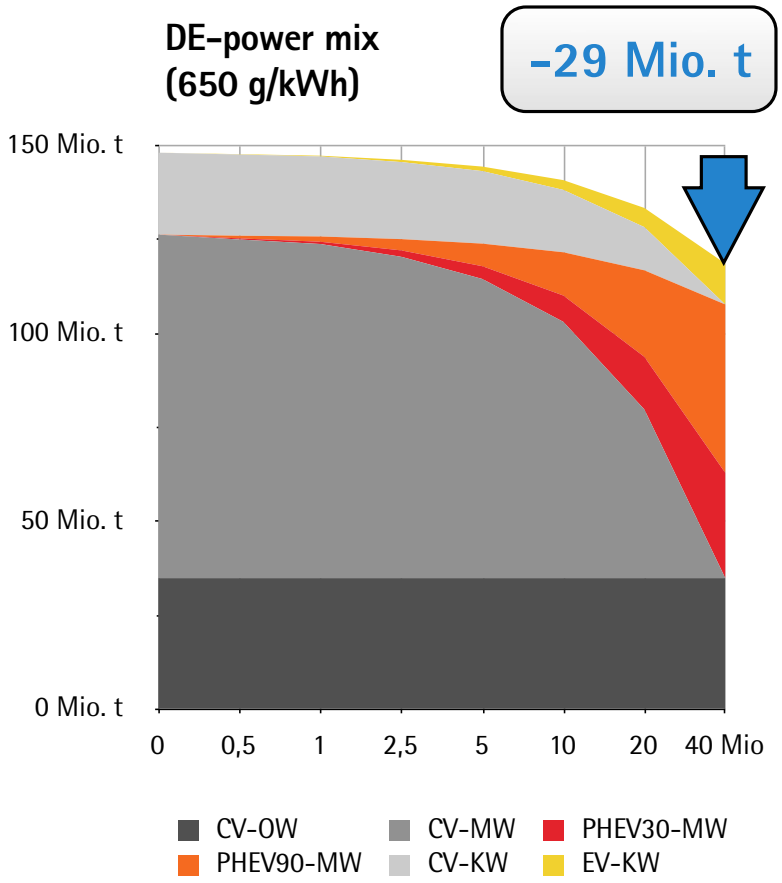

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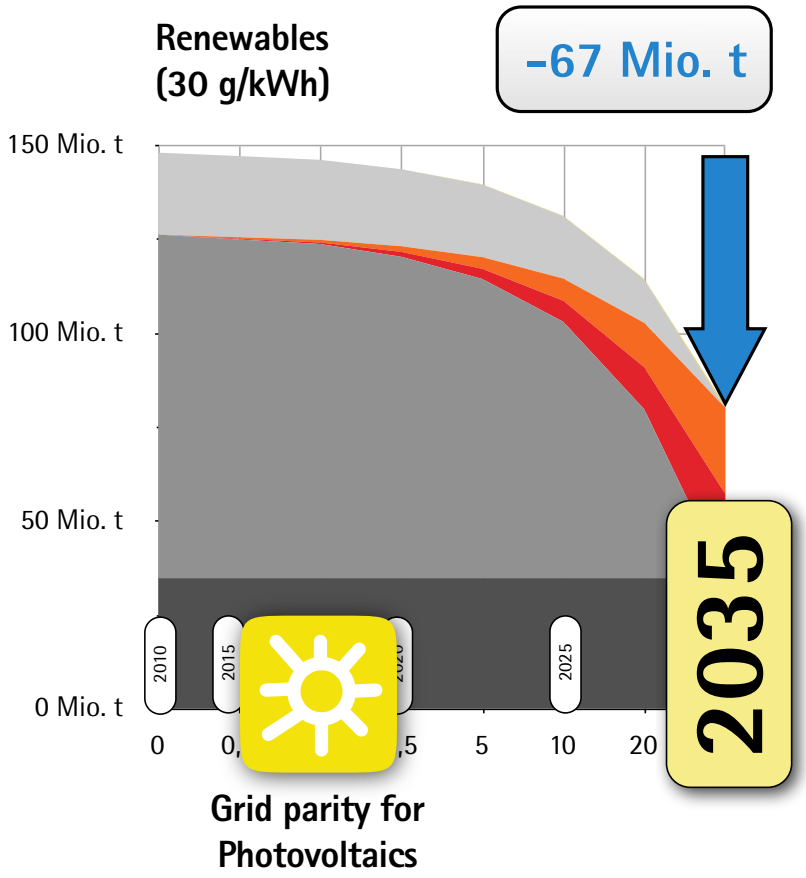

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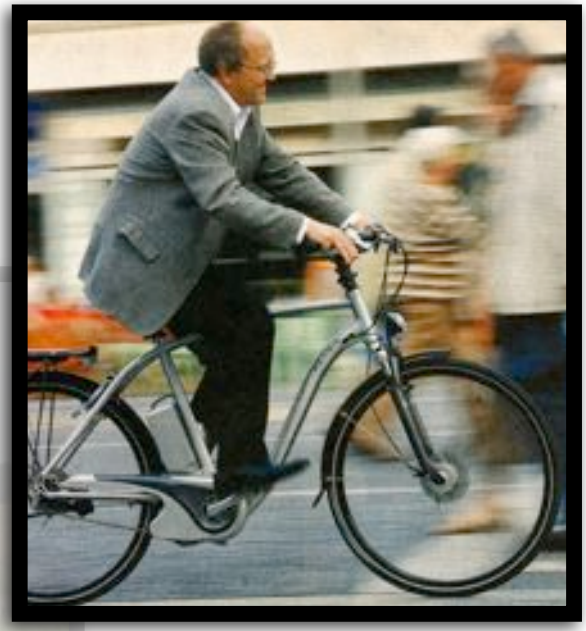
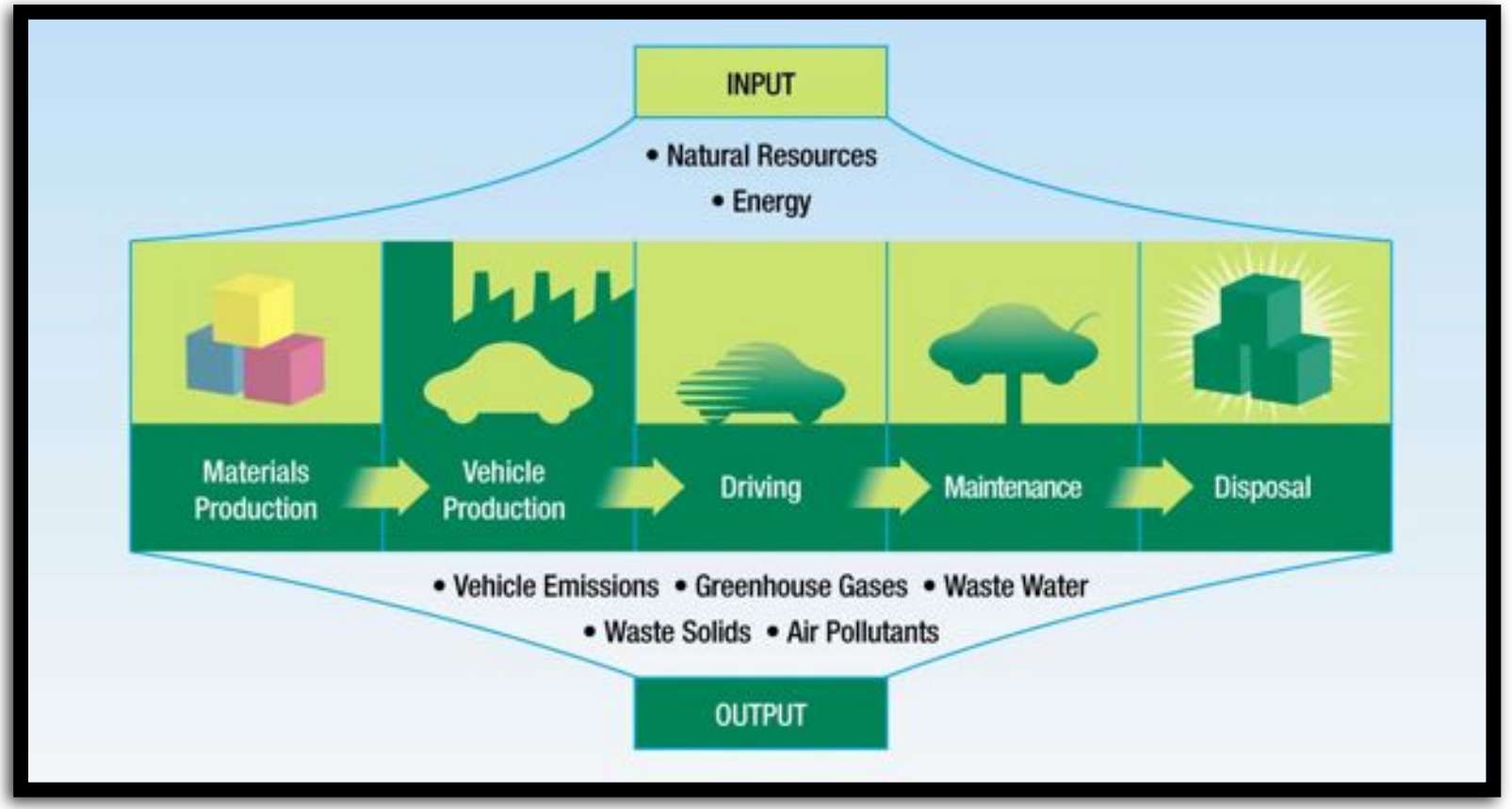
CO_2-Emissions from LEVs, Pedelecs, ... ?

xxx Mio. LEVs

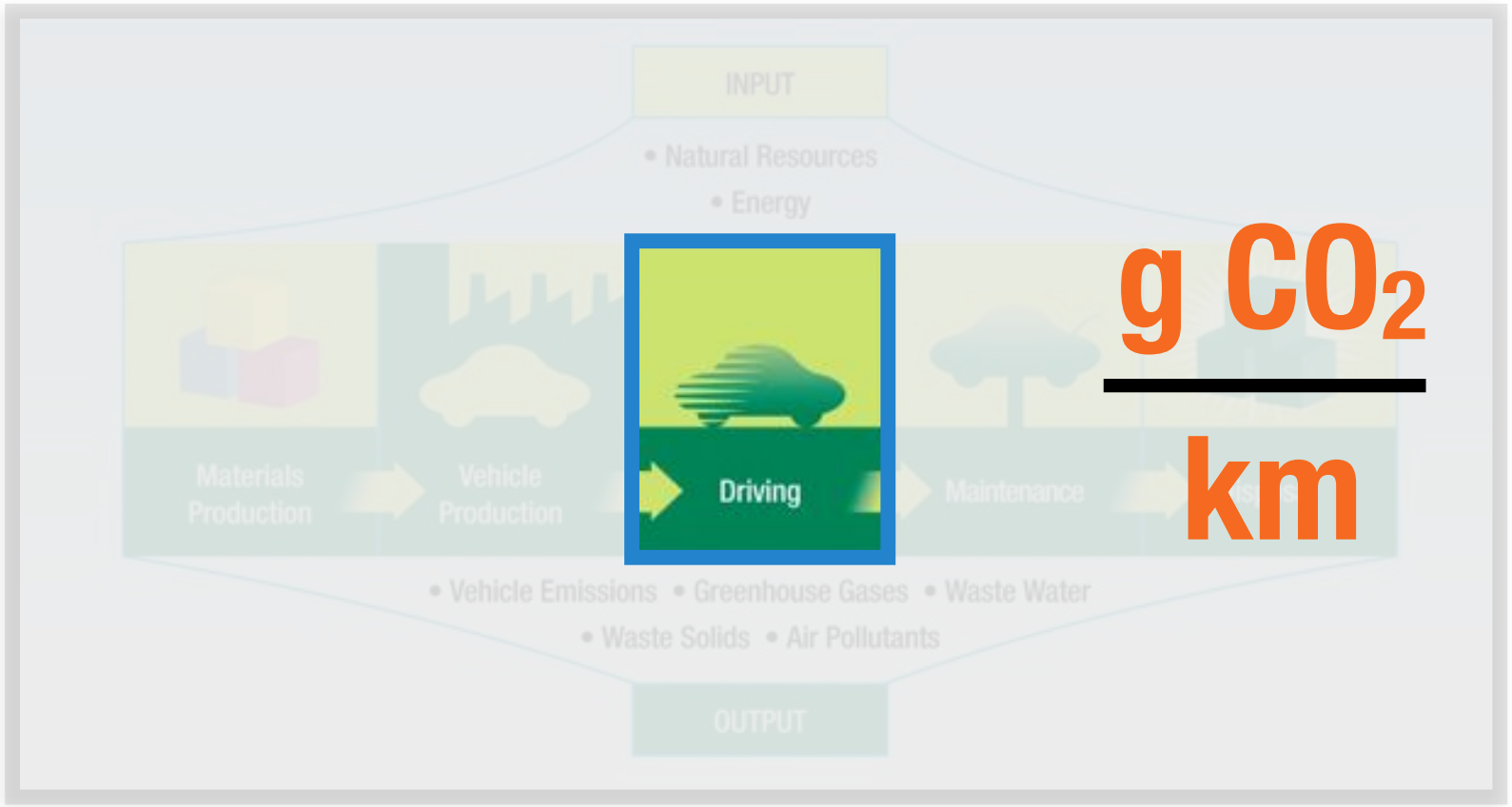


CO_2-Emissions in the Life Cycle



Quelle: Toyota Corp.

CO_2-Emissions during Driving

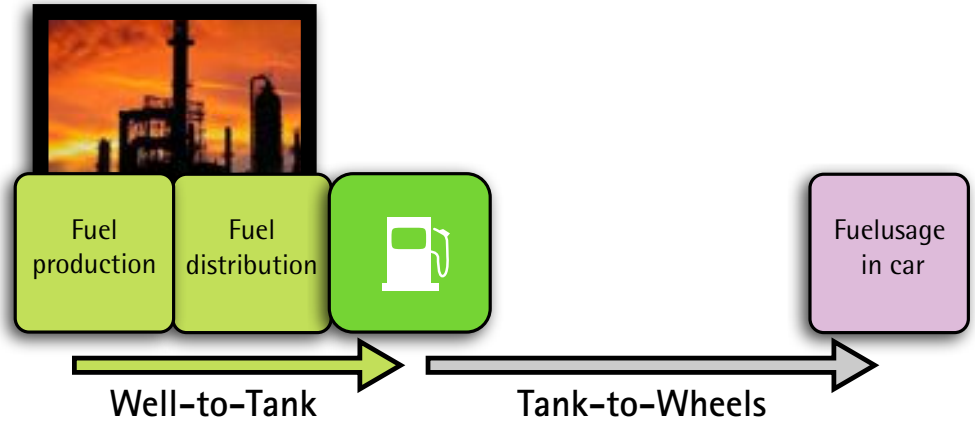


$$\frac{g\ CO_2}{km}$$

CO_2-Emissions of Automobils

$$\frac{g\ CO_2}{km}$$

CO_2-Emissions of Automobils

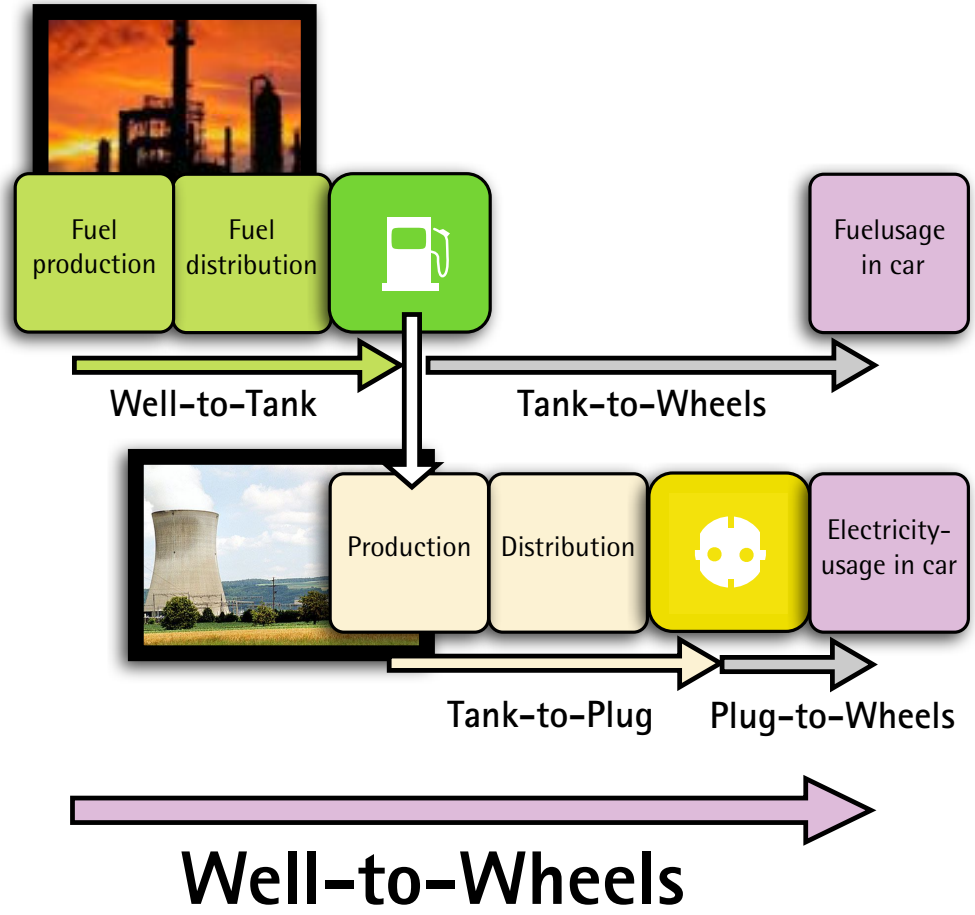


$$\frac{g\ CO_2}{km}$$

... in Germany the average is approx. 200 g/km

Well-to-Wheels

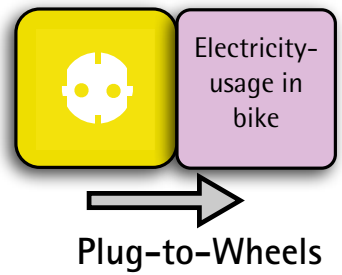
CO_2-Emissions of (PH)EV Automobils



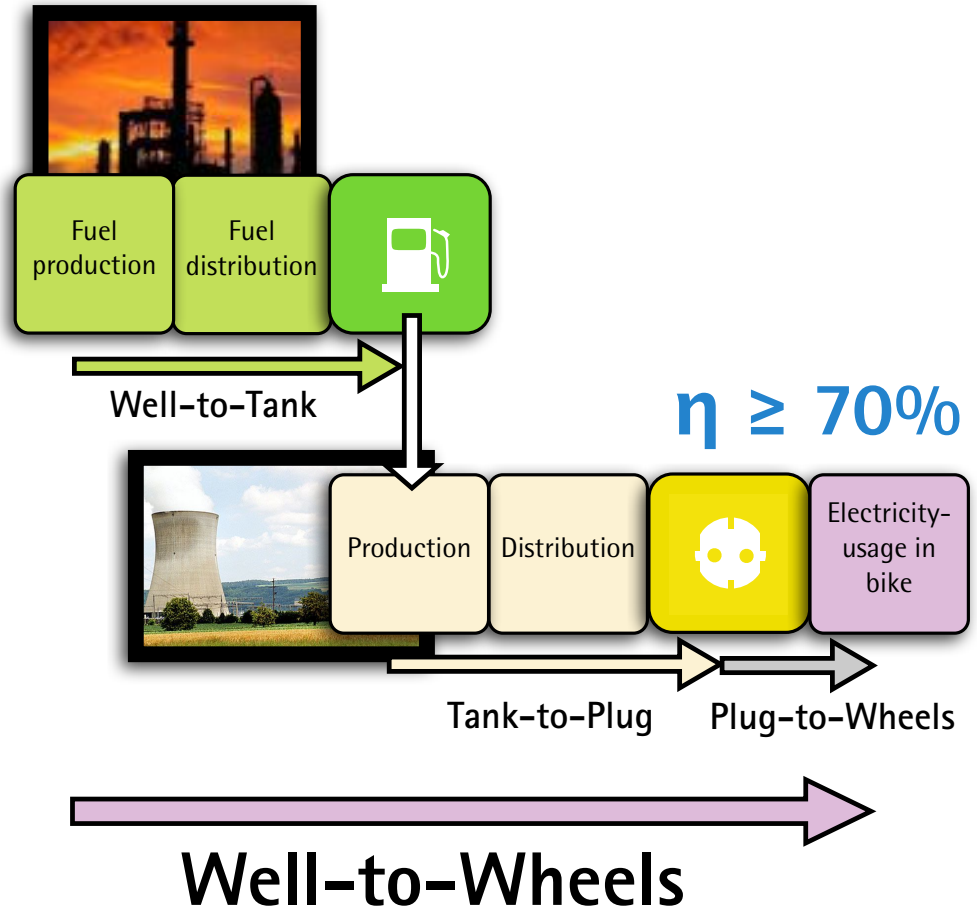
$$\frac{g\ CO_2}{km}$$

CO_2-Emissions of "E-Powered" Bikes

$$\eta \geq 70\% \qquad \frac{g\ CO_2}{km}$$



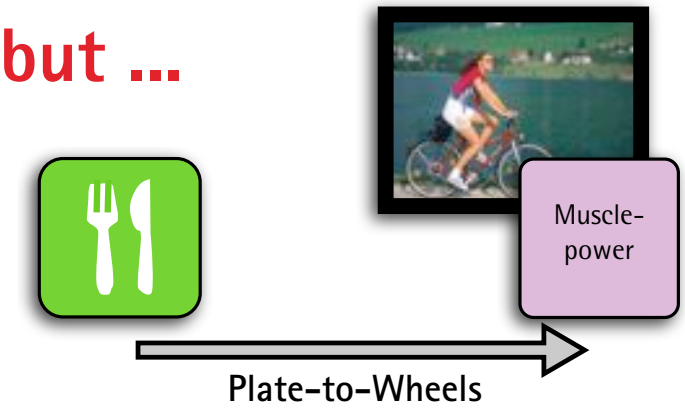
CO_2-Emissions of "E-Powered" Bikes



$$\frac{g\ CO_2}{km}$$

CO_2-Emissions of "Muscle Powered" Bikes

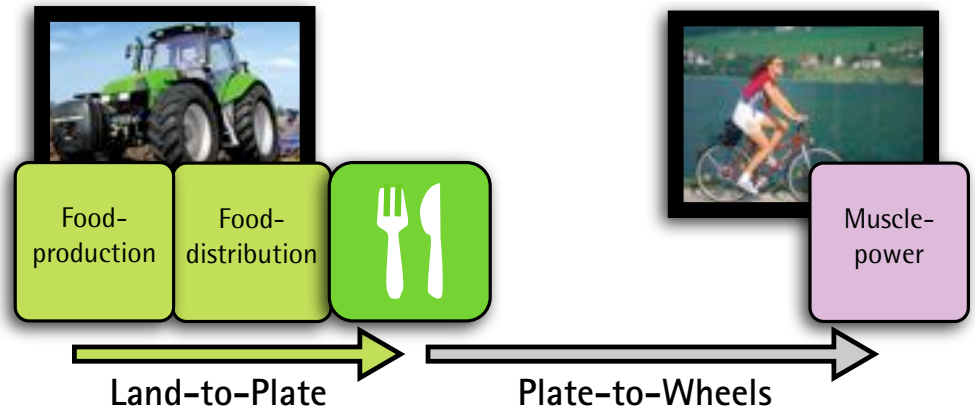
Eating is CO_2-neutral, but ...



$$\frac{g\ CO_2}{km}$$

Well-to-Wheels

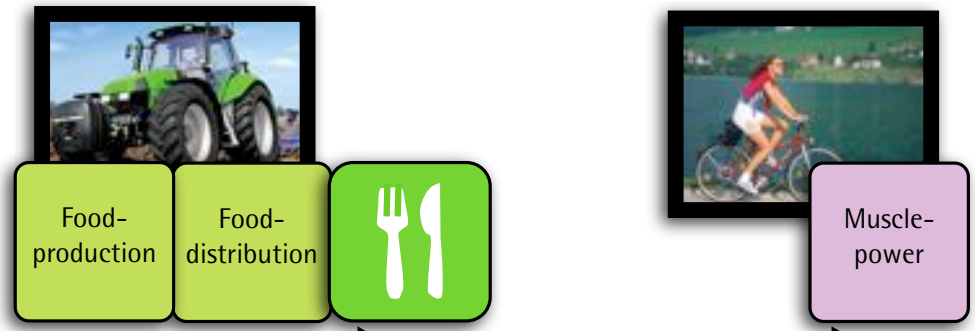
CO_2-Emissions of "Muscle Powered" Bikes



$$\frac{g\ CO_2}{km}$$

Well-to-Wheels

CO_2-Emissions of "Muscle Powered" Bikes



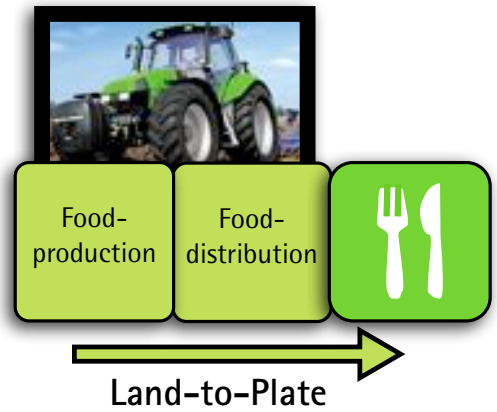
$\eta \approx 25\%$

$$\frac{g\ CO_2}{km}$$

Well-to-Wheels

Tomi Engel – Fachausschuss "Solare Mobilität"

CO_2-Emissions ...



CO_2-Emissions in Agriculture (Germany)

Livestock

Organic Fertilizer

Emissions form Land use

Land Liming

Energy usage

\+ Anorganic Fertilizer Production

Sum

Quelle: Deutscher Bundestag - Drucksache 16/5346

CO_2-Emissions in Agriculture (Germany)

CH_4

N_2O

CO_2

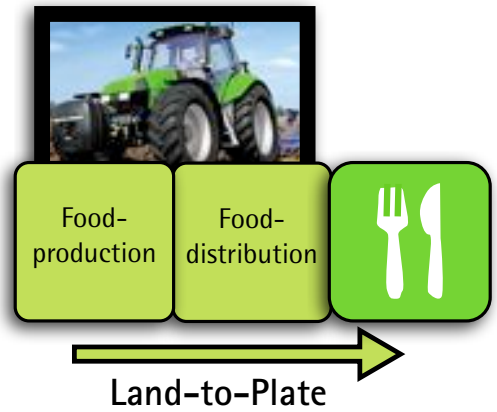
+

Livestock	**18,3**	
Organic Fertilizer	**8,1**	
Emissions form Land use	**84,2**	
Land Liming	**1,7**	
Energy usage	**6,8**	
Anorganic Fertilizer Production	**14,1**	
Sum	**133,2**	Mio t. $CO_{2\,Equiv.}$

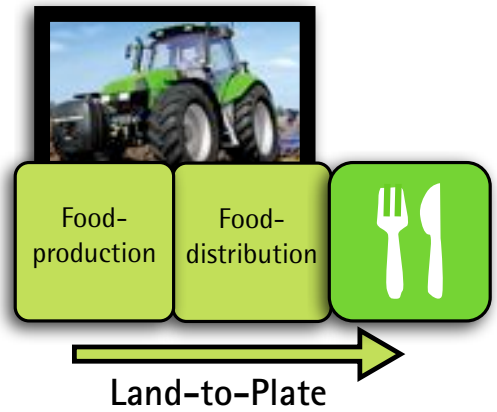
(no numbers for pesticide production, imported animal feed, ...)

Quelle: Deutscher Bundestag - Drucksache 16/5346

CO_2-Emissions ...

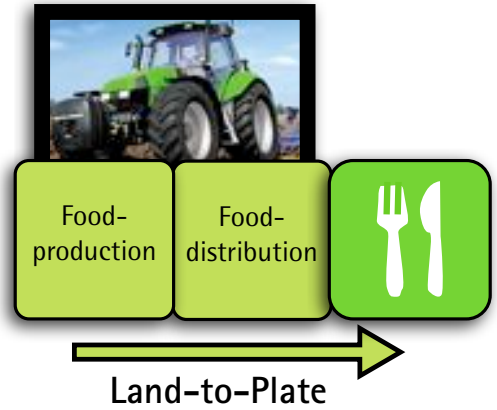


CO_2-Emissions ...



133,2 Mio t. CO_2

CO_2-Emissions ...



133,2 Mio t. CO_2

Food Consumption

?

Daily Food Consumption in Germany (Guess 1)

Deutsche Gesellschaft für Ernährung

The official statistics on food consumption in Germany

Daily Food Consumption in Germany (Guess 1)

+

Deutsche Gesellschaft für Ernährung

kcal/kg Database **fddb.info**

Daily Food Consumption in Germany (Guess 1)

Produkt	Brennwert		Fett	Kohlenhydrate	Protein	Alkohol
211 ml Pils, hell	380 KJ	91 kcal	0 g	6,3 g	0,6 g	7,6 g
456 ml Apfel schorle, Apfel	520 KJ	124 kcal	0,5 g	30,1 g	0,1 g	0 g
514 g Tee, schwarz	5 KJ	1 kcal	0 g	0 g	0 g	0 g
47 g Schokolade, Alpenmilch	1037 KJ	248 kcal	14,1 g	27,3 g	3,1 g	0 g
8 g Marmelade, Durchschnitt	88 KJ	21 kcal	0 g	4,8 g	0 g	0 g
17 g Zucker	286 KJ	68 kcal	0 g	17 g	0 g	0 g
147 g Brot, Rogensauerteig	1250 KJ	299 kcal	1,5 g	60,3 g	10,3 g	0 g
60 g Kartoffel, gegart, ohne Schale	219 KJ	52 kcal	0,1 g	12,1 g	1,1 g	0 g
50 g Reis, gekocht	272 KJ	65 kcal	0,2 g	14 g	1,3 g	0 g
34 g Tomatenmark	170 KJ	41 kcal	0 g	9,5 g	0 g	0 g
94 g Tomaten, roh	66 KJ	16 kcal	0,2 g	2,4 g	0,9 g	0 g
17 g Apfelkompott	50 KJ	12 kcal	0 g	3 g	0 g	0 g
48 g Orange, frisch	92 KJ	22 kcal	0,1 g	5,5 g	0,3 g	0 g
89 g Apfel, frisch	194 KJ	46 kcal	0,2 g	12,3 g	0,2 g	0 g
6 ml Olivenöl	209 KJ	50 kcal	5,5 g	0 g	0 g	0 g
14 g Margarine	413 KJ	99 kcal	11,2 g	0 g	0 g	0 g
14 g Butter	427 KJ	102 kcal	11,5 g	0,3 g	0,1 g	0 g
60 ml Bexlight Joghurt Drink light, Himbeer-L	98 KJ	23 kcal	0,1 g	3,8 g	1,9 g	0 g
38 g Frischkäse, Kräuter	444 KJ	106 kcal	10,3 g	1,1 g	2,3 g	0 g
150 ml Vollmilch, 3.5% Fett	434 KJ	104 kcal	5,3 g	7,5 g	6 g	0 g
18 g Ei, vom Huhn	117 KJ	28 kcal	1,8 g	0 g	1,6 g	0 g
60 g Pfeffrige Salami	799 KJ	191 kcal	14,4 g	1,2 g	14,4 g	0 g
61 g Kalbfleisch, Filet	275 KJ	66 kcal	0,6 g	0 g	13,4 g	0 g
15 g Lachs Filets	124 KJ	30 kcal	2,1 g	0 g	2,8 g	0 g
	7966 KJ	1903 kcal	**79,4 g**	**218,5 g**	**60,6 g**	**7,6 g**

fddb.info

Quelle: Deutsche Gesellschaft für Ernährung und http://fddb.info

Tomi Engel – Fachausschuss "Solare Mobilität"

Daily Food Consumption in Germany (Guess 1)

light work

			Fett	Kohlenhydrate	Protein	Alkohol
			0 g	6,3 g	0,6 g	7,6 g
			0,5 g	30,1 g	0,1 g	0 g
			0 g	0 g	0 g	0 g
			14,1 g	27,3 g	3,1 g	0 g
			0 g	4,8 g	0 g	0 g
			0 g	17 g	0 g	0 g
			1,5 g	60,3 g	10,3 g	0 g
			0,1 g	12,1 g	1,1 g	0 g
			0,2 g	14 g	1,3 g	0 g
			0 g	9,5 g	0 g	0 g
			0,2 g	2,4 g	0,9 g	0 g
			0 g	3 g	0 g	0 g
			0,1 g	5,5 g	0,3 g	0 g
			0,2 g	12,3 g	0,2 g	0 g
			5,5 g	0 g	0 g	0 g
			11,2 g	0 g	0 g	0 g
14 g Butter	427 KJ	102 kcal	11,5 g	0,3 g	0,1 g	0 g
60 ml [illegible] Joghurt Drink light, Himbeer-L	98 KJ	23 kcal	0,1 g	3,8 g	1,9 g	0 g
38 g [illegible]	444 KJ	106 kcal	10,3 g	1,1 g	2,3 g	0 g
150 ml Vollmilch, 3.5% Fett	434 KJ	104 kcal	5,3 g	7,5 g	6 g	0 g
18 g Ei, vom Huhn	117 KJ	28 kcal	1,8 g	0 g	1,6 g	0 g
60 g Pfeffrige Salami						
61 g Kalbfleisch, Filet						
15 g Lachs Filets						

7966 KJ 1903 kcal

Quelle: Deutsche Gesellschaft für Ernährung und http://fddb.info

Daily Food Consumption in Germany (Guess 2)

light work

2050 kcal/d

Basal metabolic rate (BMR)

for a Person (72 kg, 175 cm, age 40) = 1650 kcal/d

Quelle: www.bmi-calculator.net and many others ...

Daily Food Consumption in Germany (Guess 2)

light work

2050 kcal/d

hard work

2850 kcal/d

Basal metabolic rate (BMR)

for a Person (72 kg, 175 cm, age 40) = 1650 kcal/d

Quelle: www.bmi-calculator.net and many others ...

Daily Food Consumption in Germany (Guess 2)

light work	average	hard work
2050 kcal/d	2500 kcal/d	2850 kcal/d

Basal metabolic rate (BMR)

for a Person (72 kg, 175 cm, age 40) = 1650 kcal/d

Quelle: www.bmi-calculator.net and many others ...

Daily Food Consumption in Germany (Guess 2)

light work

100 Watt

average

121 Watt

hard work

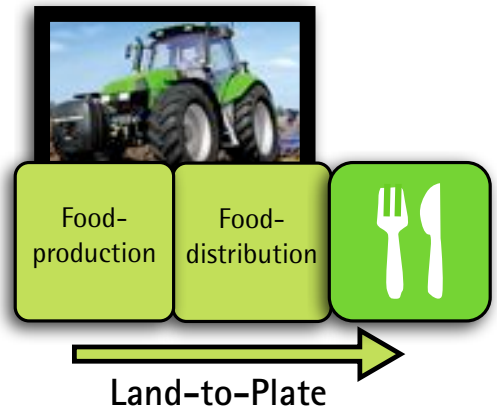
138 Watt

Basal metabolic rate (BMR)

for a Person (72 kg, 175 cm, age 40) = **78 Watt**

Quelle: www.bmi-calculator.net and many others ...

Food related CO_2-Emissions in Germany



133,2 Mio t. CO_2

Food Consumption

?

Food related CO_2-Emissions in Germany

133 Mio t CO2/a / 82 Mio. People = 1,62 t CO2/a Person

2000 kcal/d * 365 d/a = 730.000 kcal/a

light work

Food related CO_2-Emissions in Germany

133 Mio t CO2/a / 82 Mio. People = 1,62 t CO2/a Person

2000 kcal/d
light work
* 365 d/a = 730.000 kcal/a

2,219 g CO2/kcal

Tomi Engel – Fachausschuss "Solare Mobilität"

Food related CO_2-Emissions in Germany

133 Mio t CO2/a / 82 Mio. People = 1,62 t CO2/a Person

2500 kcal/d * 365 d/a = 912.500 kcal/a

average

Food related CO_2-Emissions in Germany

133 Mio t CO2/a / 82 Mio. People = 1,62 t CO2/a Person

2500 kcal/d (average) * 365 d/a = 912.500 kcal/a

912.500 kcal/a / 1,775 g CO2/kcal

Tomi Engel – Fachausschuss "Solare Mobilität"

Food related CO_2-Emissions in Germany

worst case ... more likely than the **best case**

best case ... will draw a more climate friendly picture

-20%

best case ≈ 1,775 g CO2/kcal

worst case ≈ 2,219 g CO2/kcal

Food related CO_2-Emissions in Germany

BEWARE! **Your milage will vary**

Food based emissions can vary extemely depending on the type of agriculture practice, food mix, etc.

1,52 g CO2/Wh = **best case ≈** 1,775 g CO2/kcal

Food related CO_2-Emissions in Germany

1500 g CO2/kWh

Average German diet

7030 g CO2/kWh

Beef

11371 g CO2/kg
1390 kcal/kg

1100 g CO2/kWh

Milk

881 g CO2/kg
690 kcal/kg

290 g CO2/kWh

Bread

648 g CO2/kg
1910 kcal/kg

162 g CO2/kWh

Potatoes

136 g CO2/kg
720 kcal/kg

Quelle: Öko-Institut Nov 2007

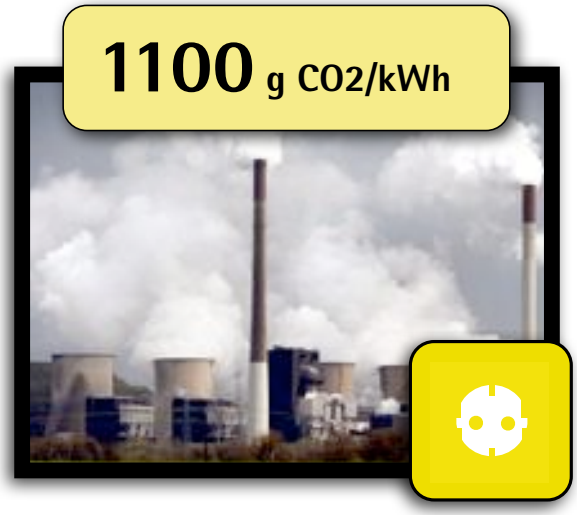
Energy related CO_2-Emissions in Germany

162 g CO2/kWh

Potatoes

Quelle: GEMIS Database

Energy related CO_2-Emissions in Germany

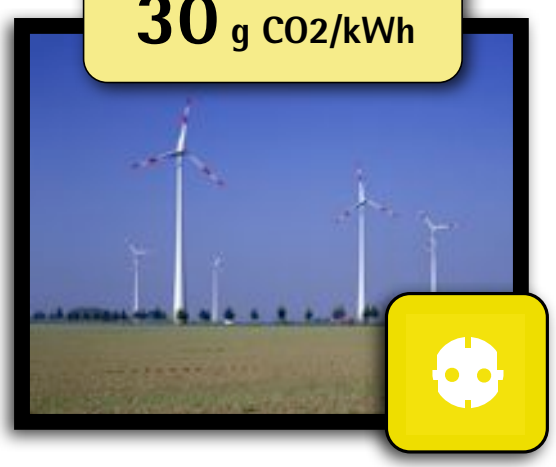


162 g CO2/kWh

Potatoes

Quelle: GEMIS Database

Energy related CO_2-Emissions in Germany

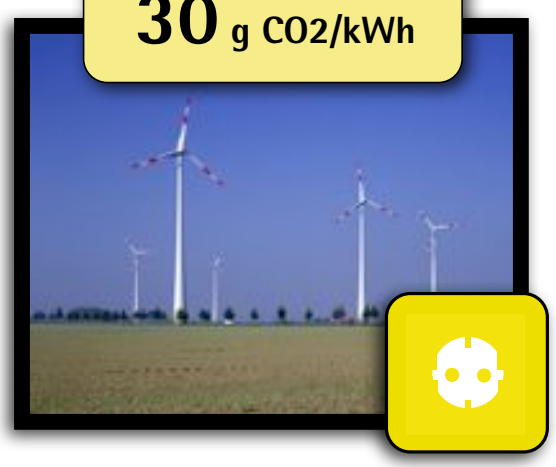


162 g CO2/kWh

Potatoes

Quelle: GEMIS Database

Energy related CO_2-Emissions in Germany

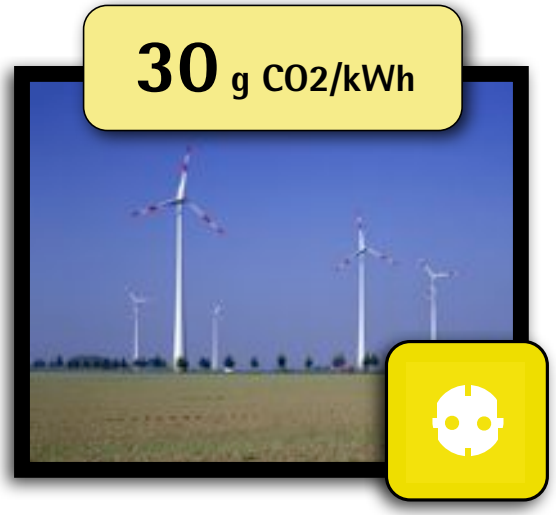


650 g CO2/kWh

= German electricity mix

Quelle: GEMIS Database

Energy related CO_2-Emissions in Germany



How Can We Compare These?

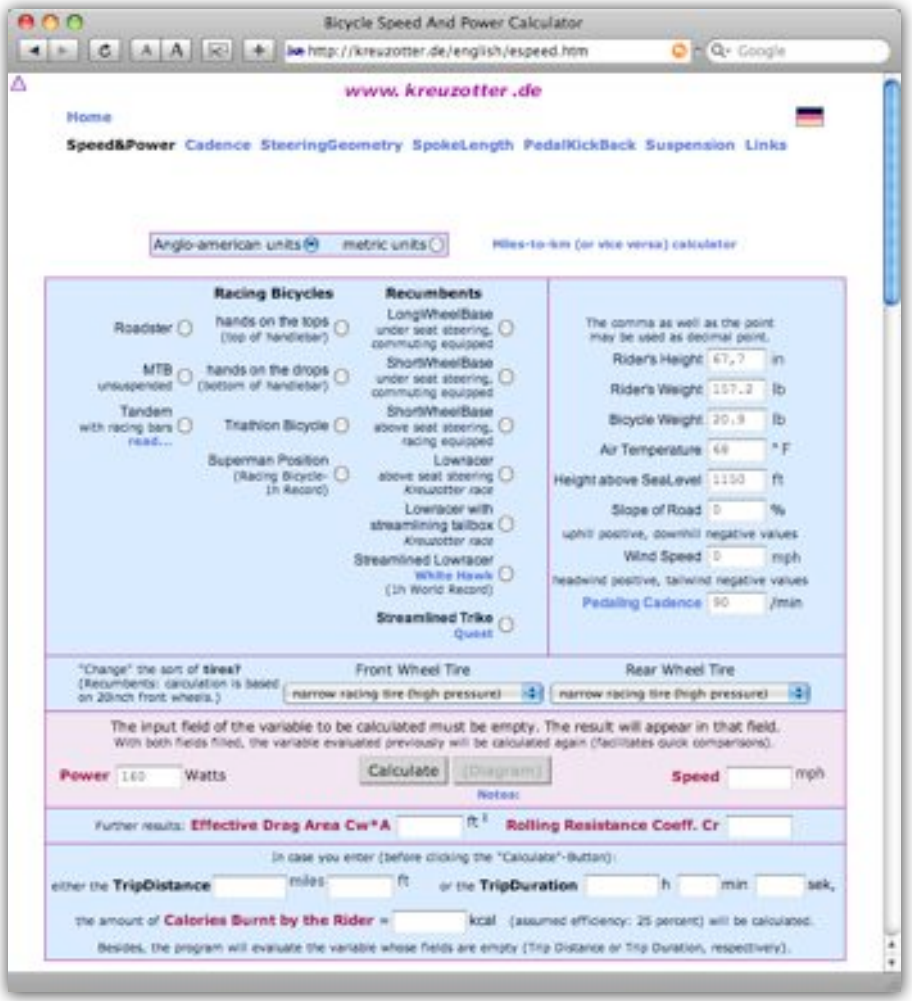
(we answer this question later)

Cycling Theory

Touring
(18 kg)

MTB
(12 kg)

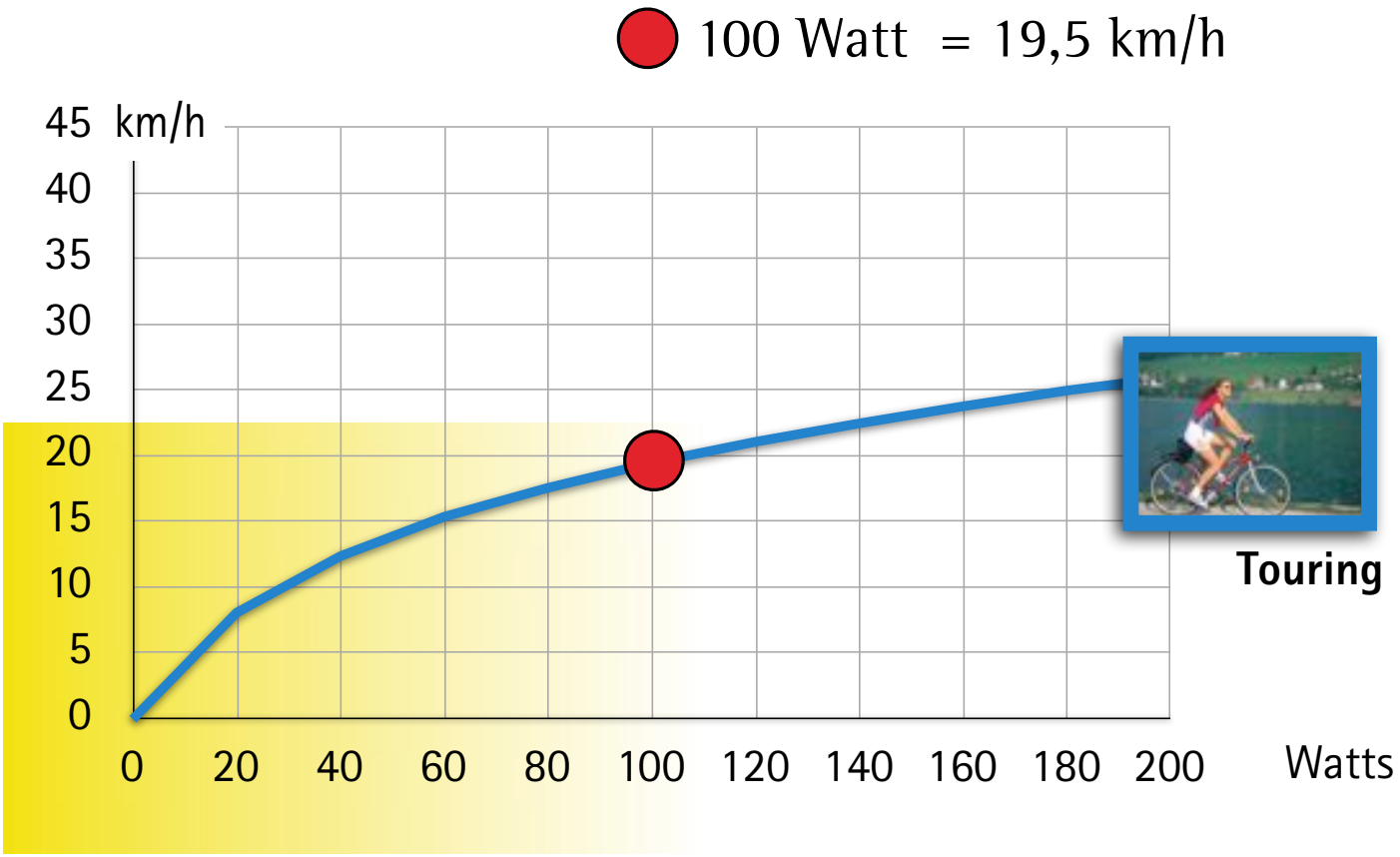
Recumbent
(12 kg)



www.kreuzotter.de

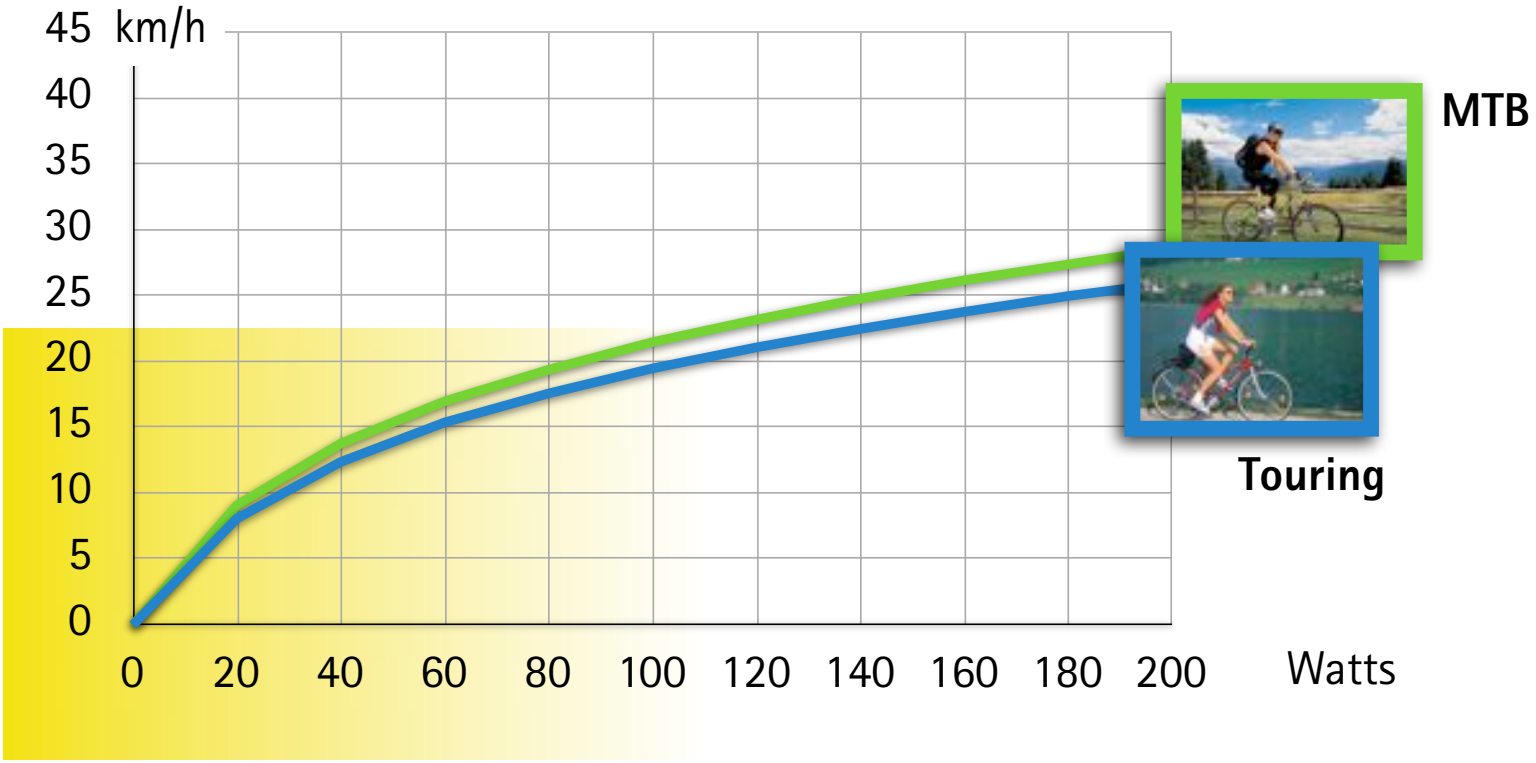
Quelle: kreuzotter.de

Cycling Theory ... Speed



Quelle: kreuzotter.de

Cycling Theory ... Speed



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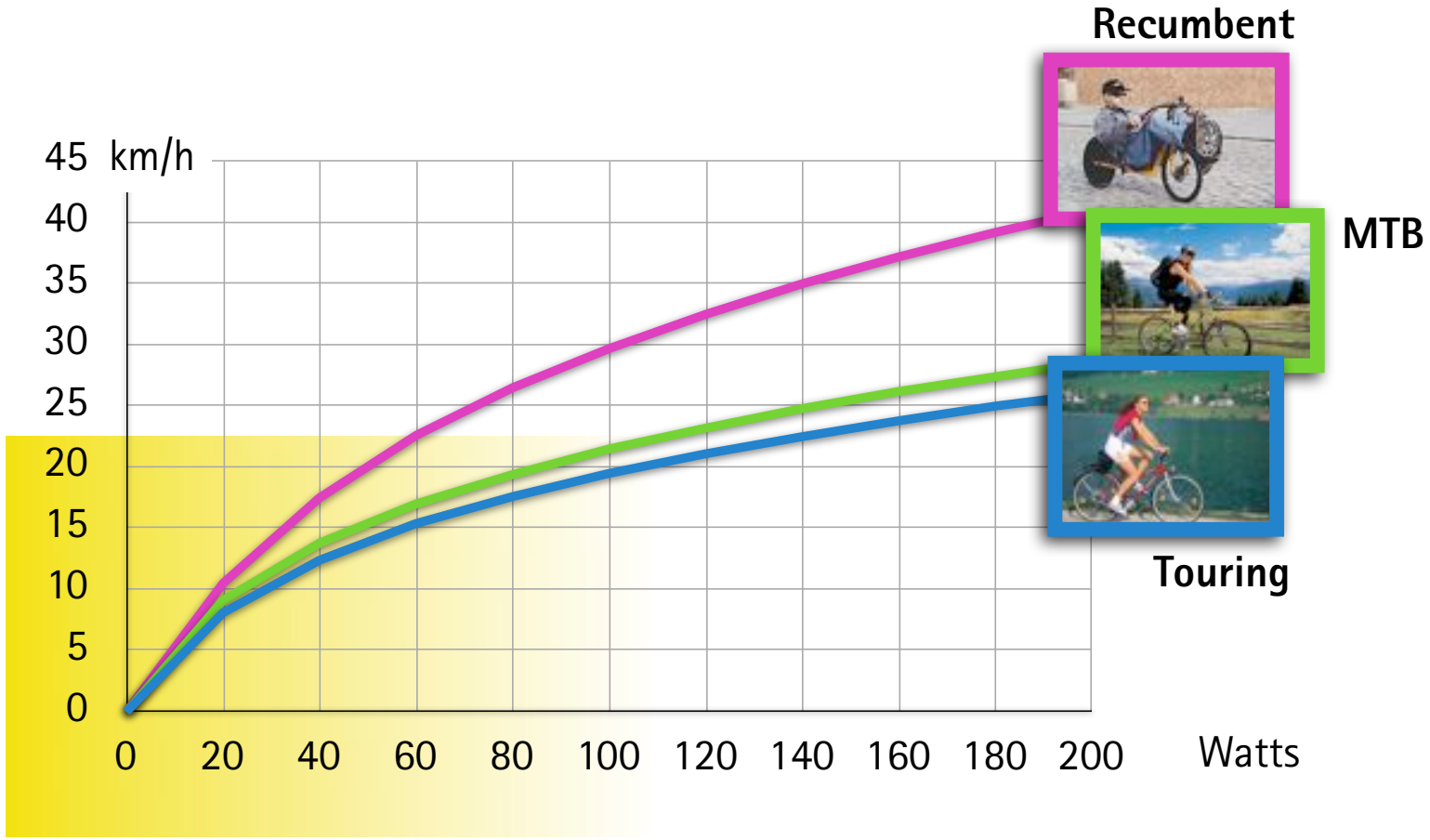
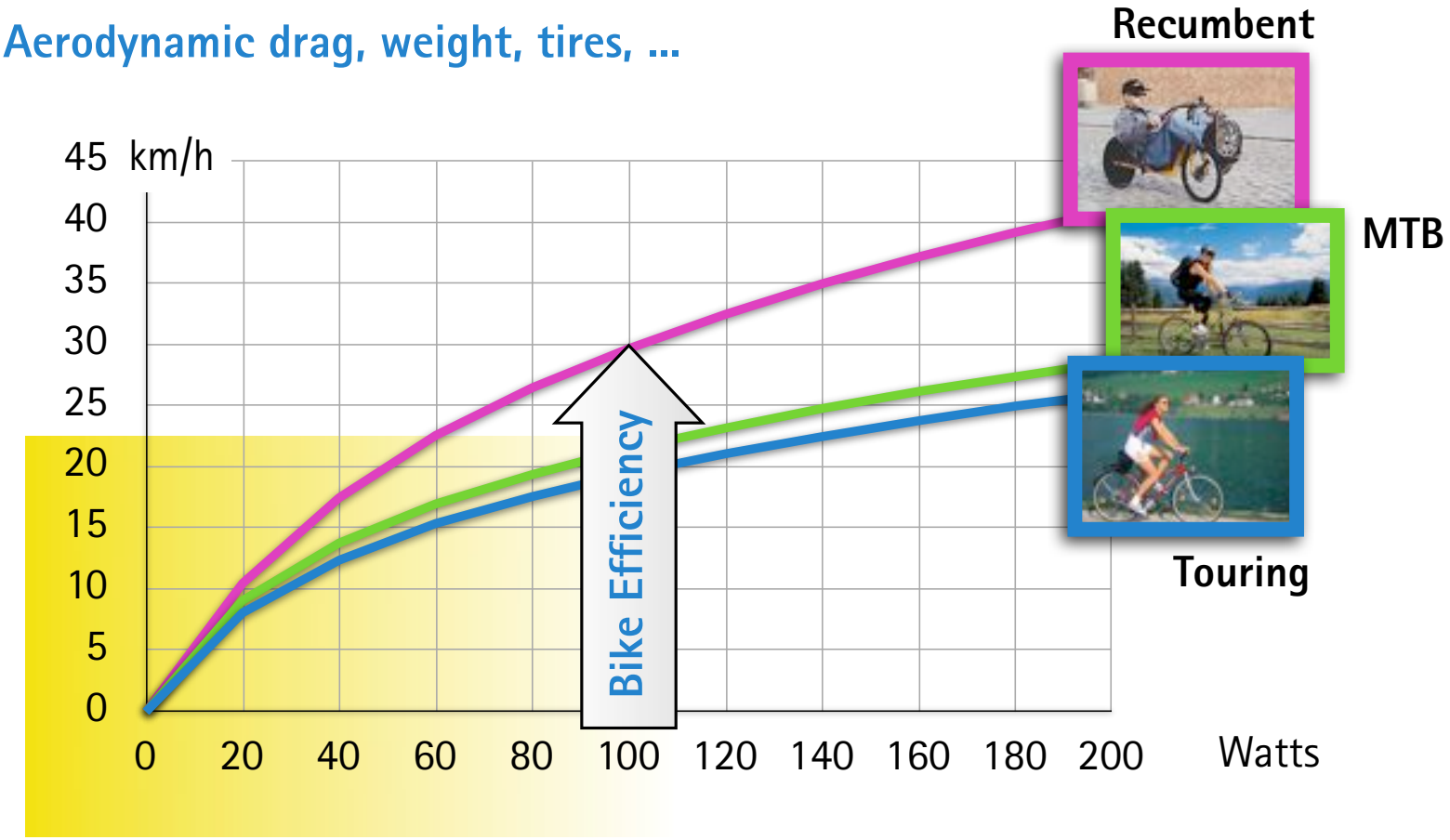
Cycling Theory ... Speed



Quelle: kreuzotter.de

Cycling Theory ... Speed

Aerodynamic drag, weight, tires, ...



Quelle: kreuzotter.de

Cycling Theory ... Speed

... but still the same energy source!

Quelle: kreuzotter.de

Cycling Theory ... Power

Flat

Required Power: **60 Watt**

Hill (8 %)

360 Watt

Rider: 175 cm, 72 kg
Bike: 18 kg
Speed: 15 km/h

Cycling Theory ... Power

Flat

Required Power: **60 Watt**

Hill (8 %)

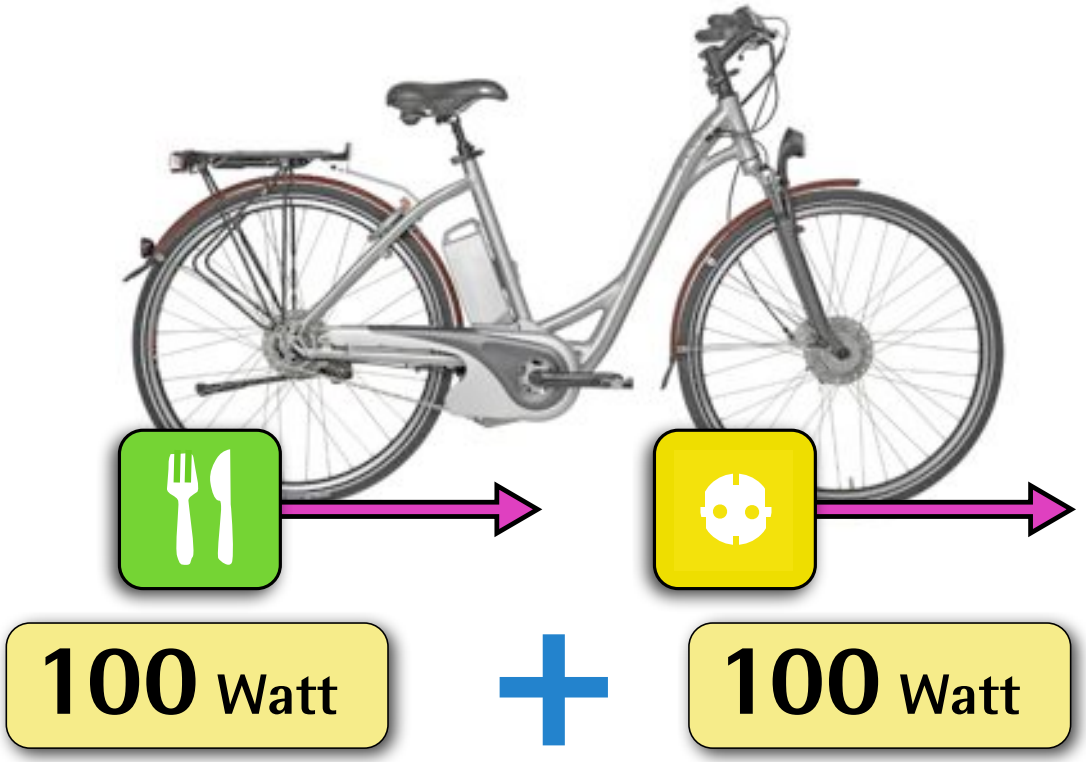
360 Watt

"Amsterdam Problem"

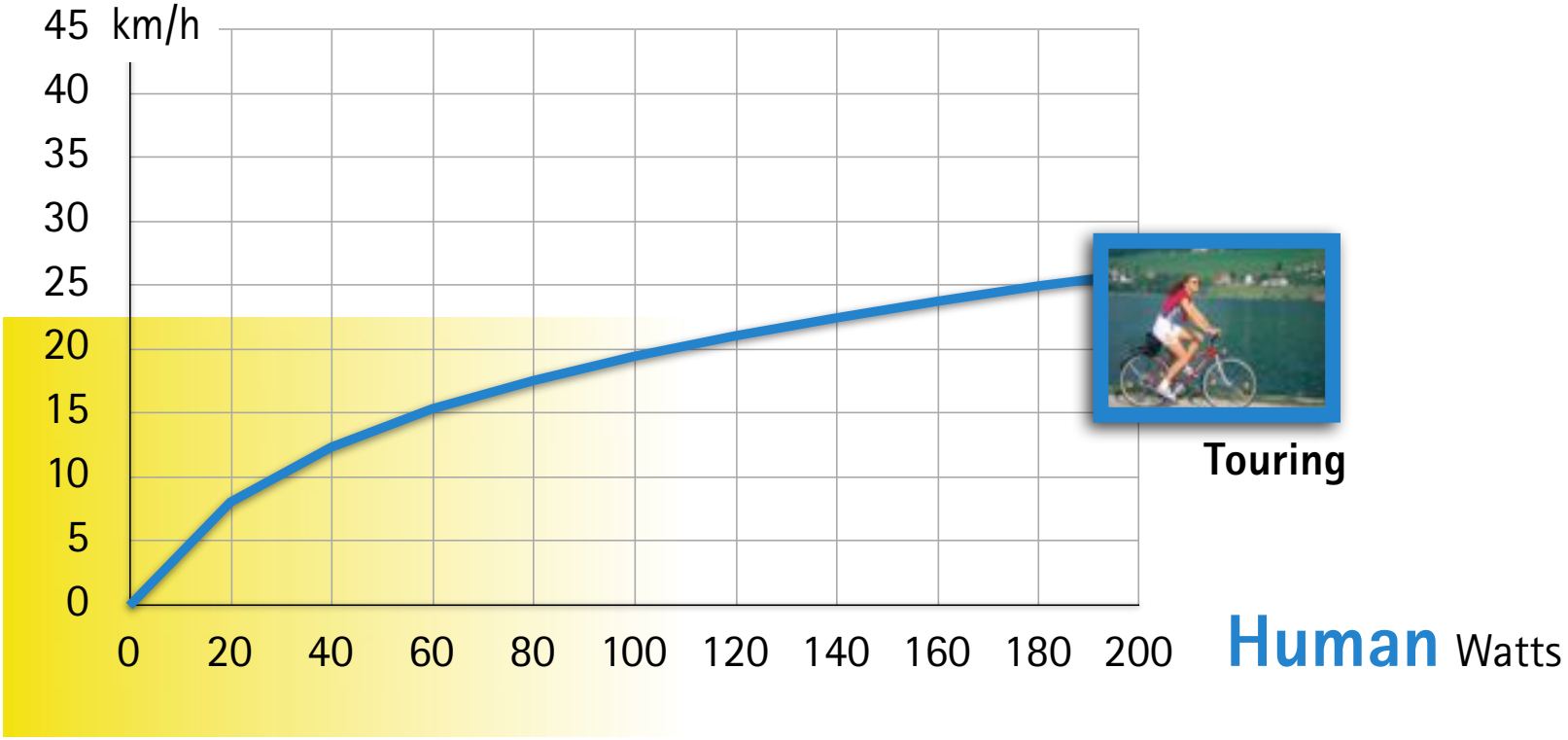
Hey .. what about those nasty head winds??

"Stuttgart Problem"

Cycling Theory ... Assistance Factor

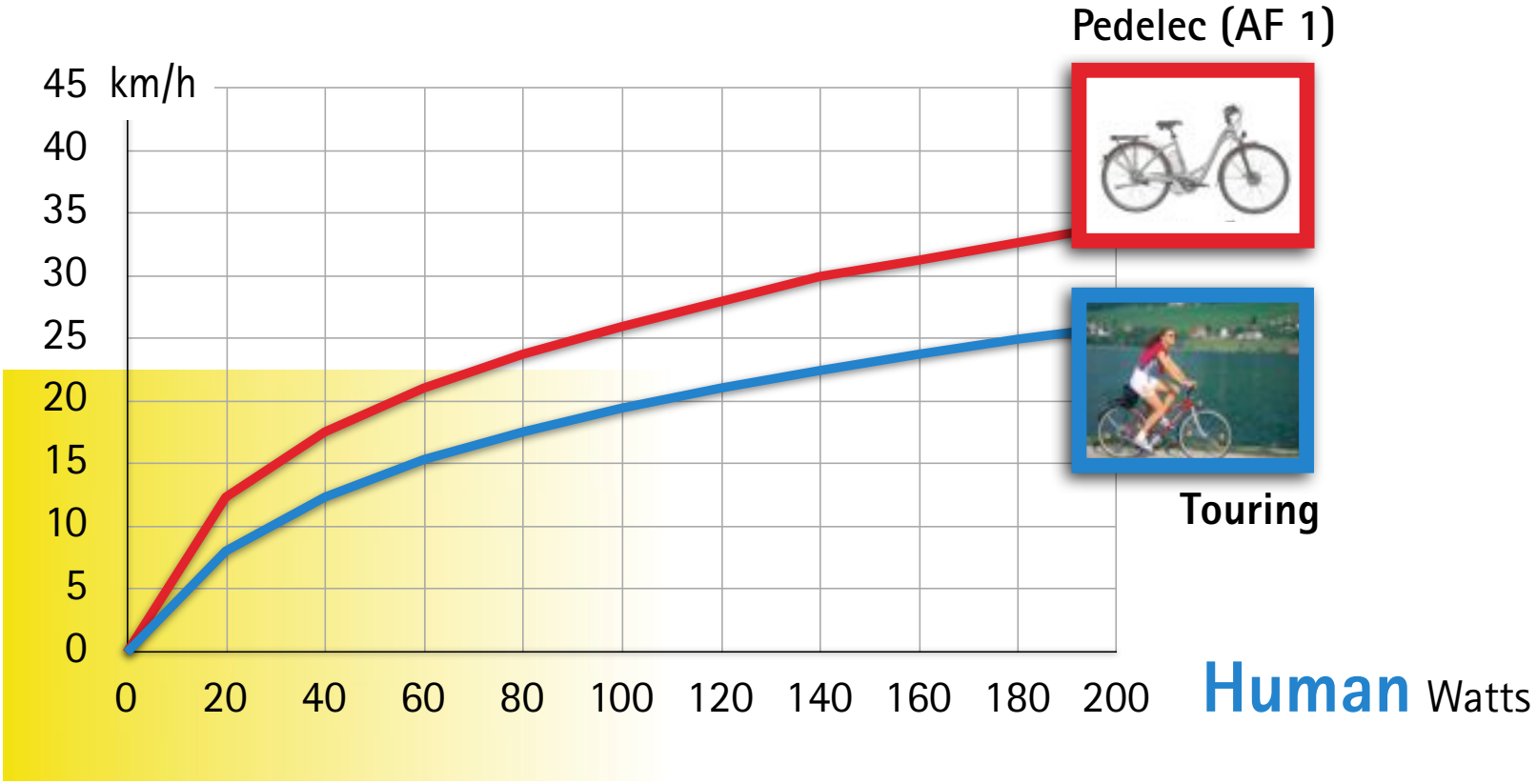


Cycling Theory ... Speed



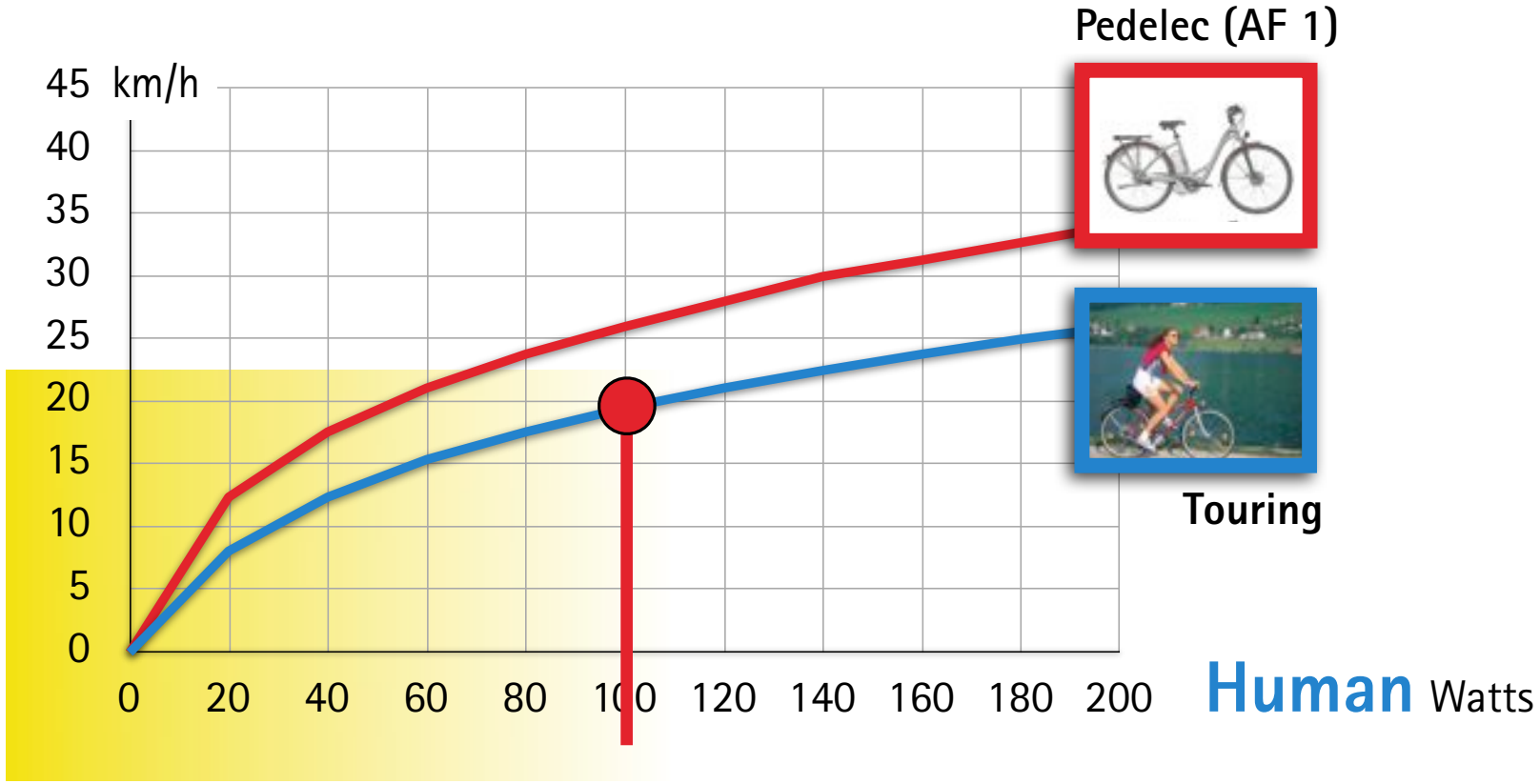
Quelle: kreuzotter.de

Cycling Theory ... Speed



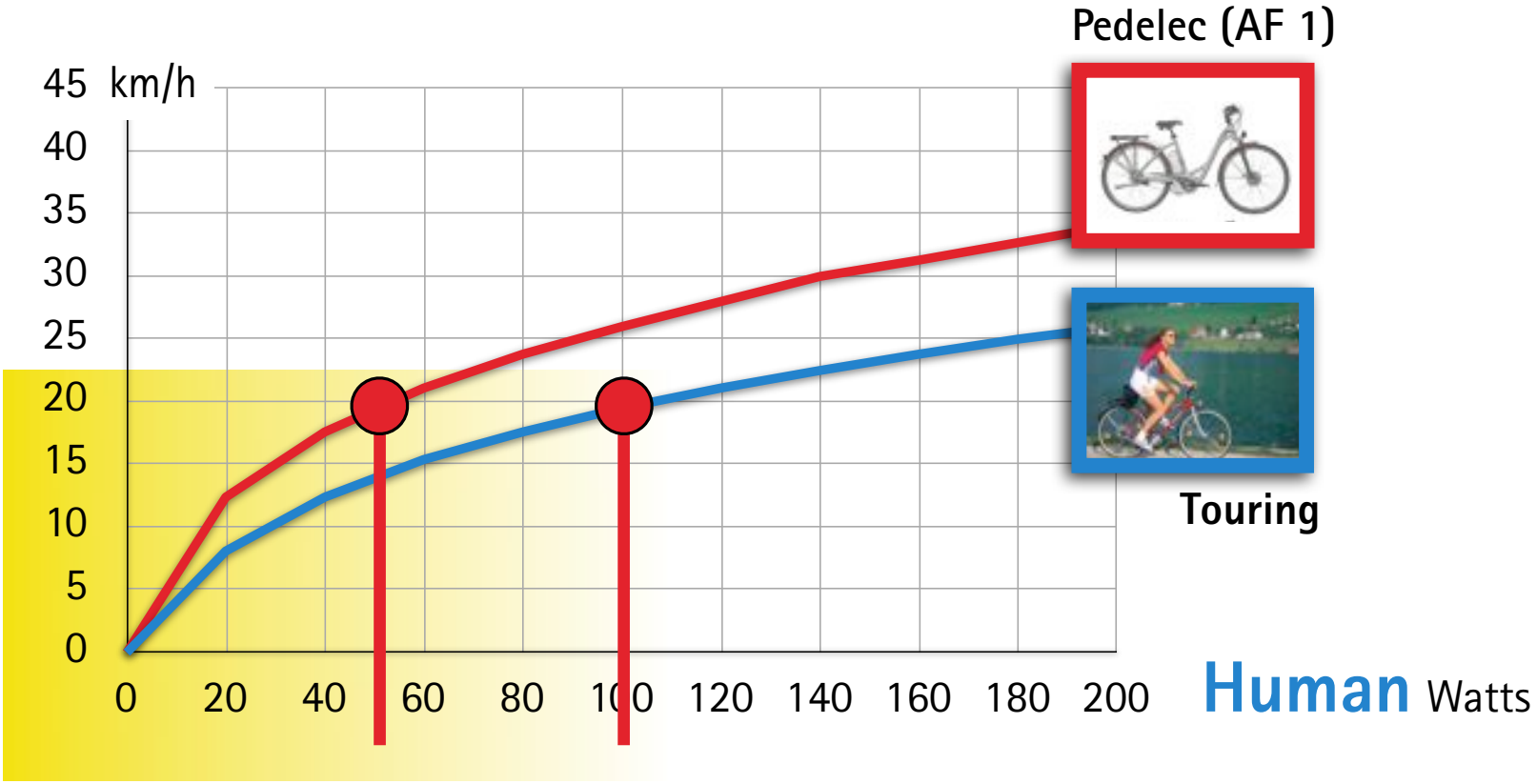
Quelle: kreuzotter.de

Cycling Theory ... Speed



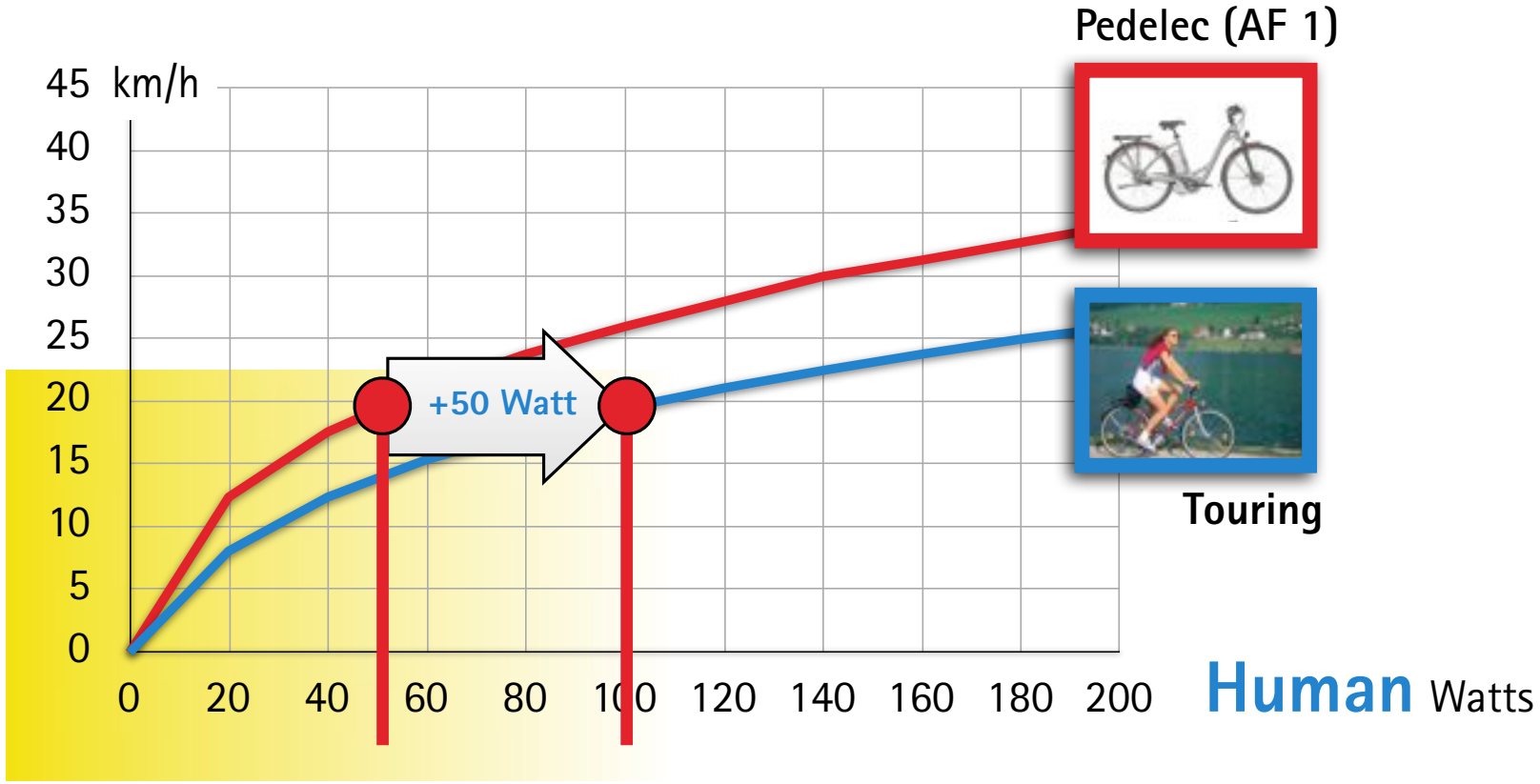
Quelle: kreuzotter.de

Cycling Theory ... Speed



Quelle: kreuzotter.de

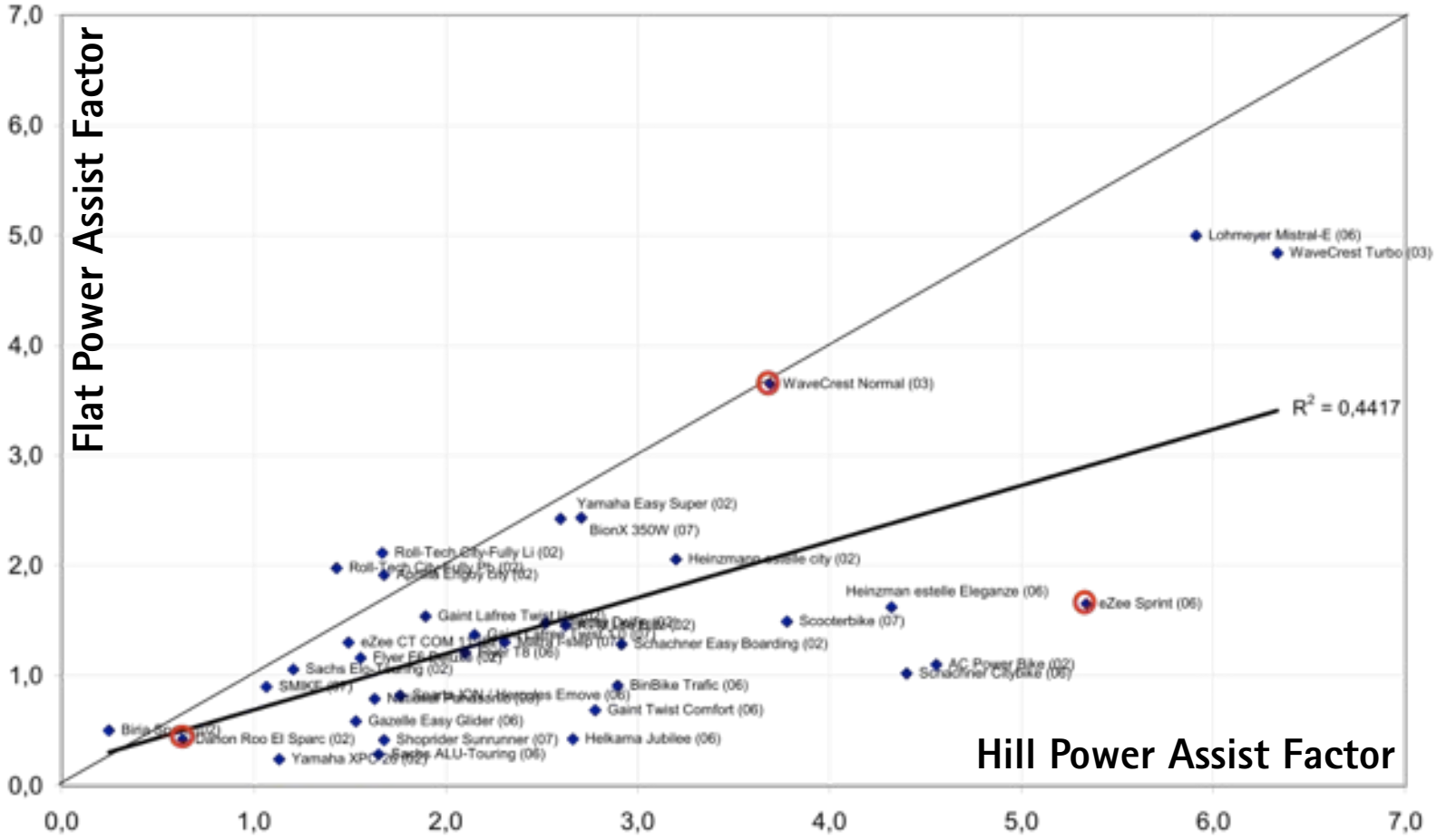
Cycling Theory ... Speed



Quelle: kreuzotter.de

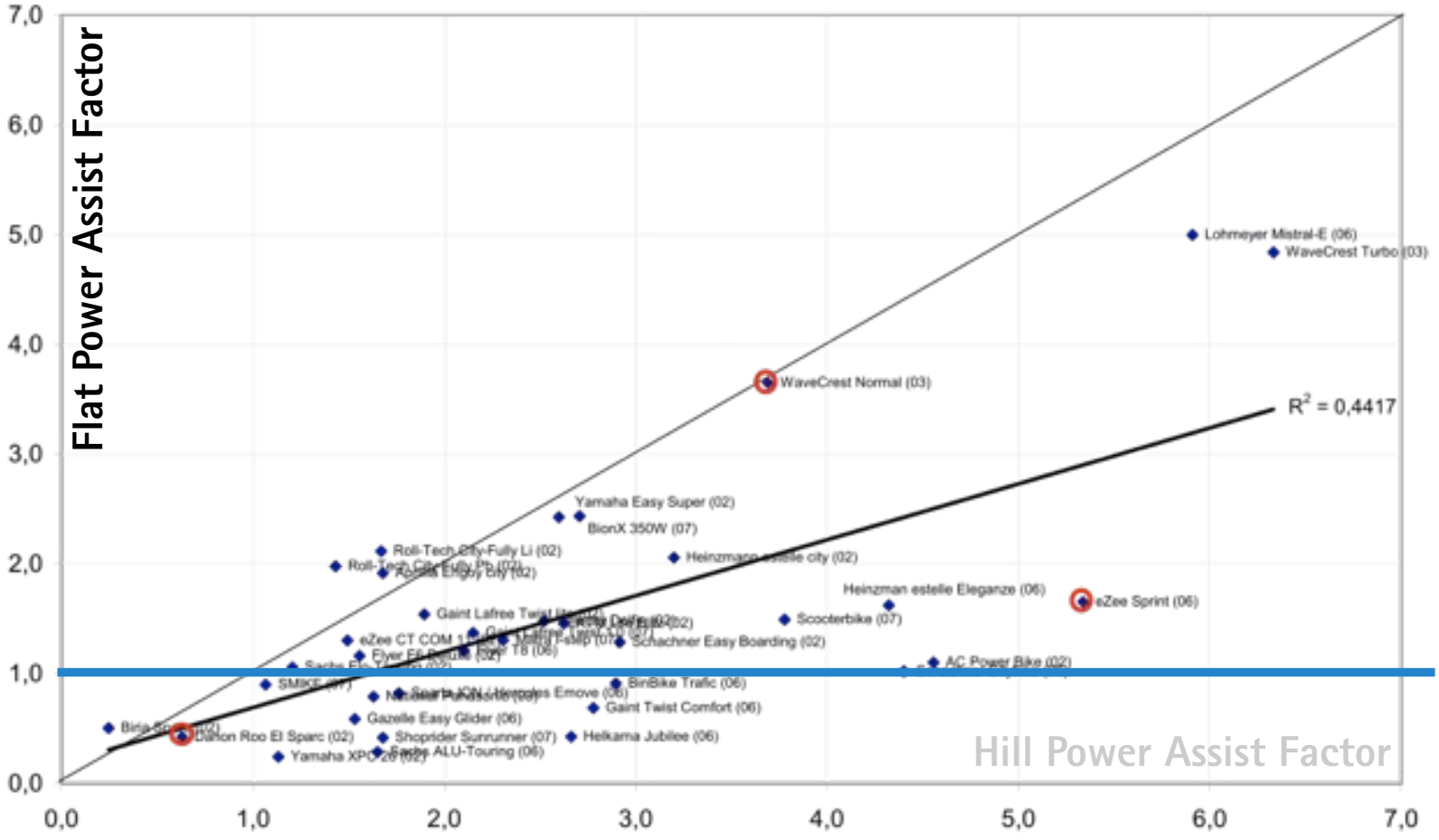
Tomi Engel – Fachausschuss "Solare Mobilität"

Assistance Faktor ... Reality



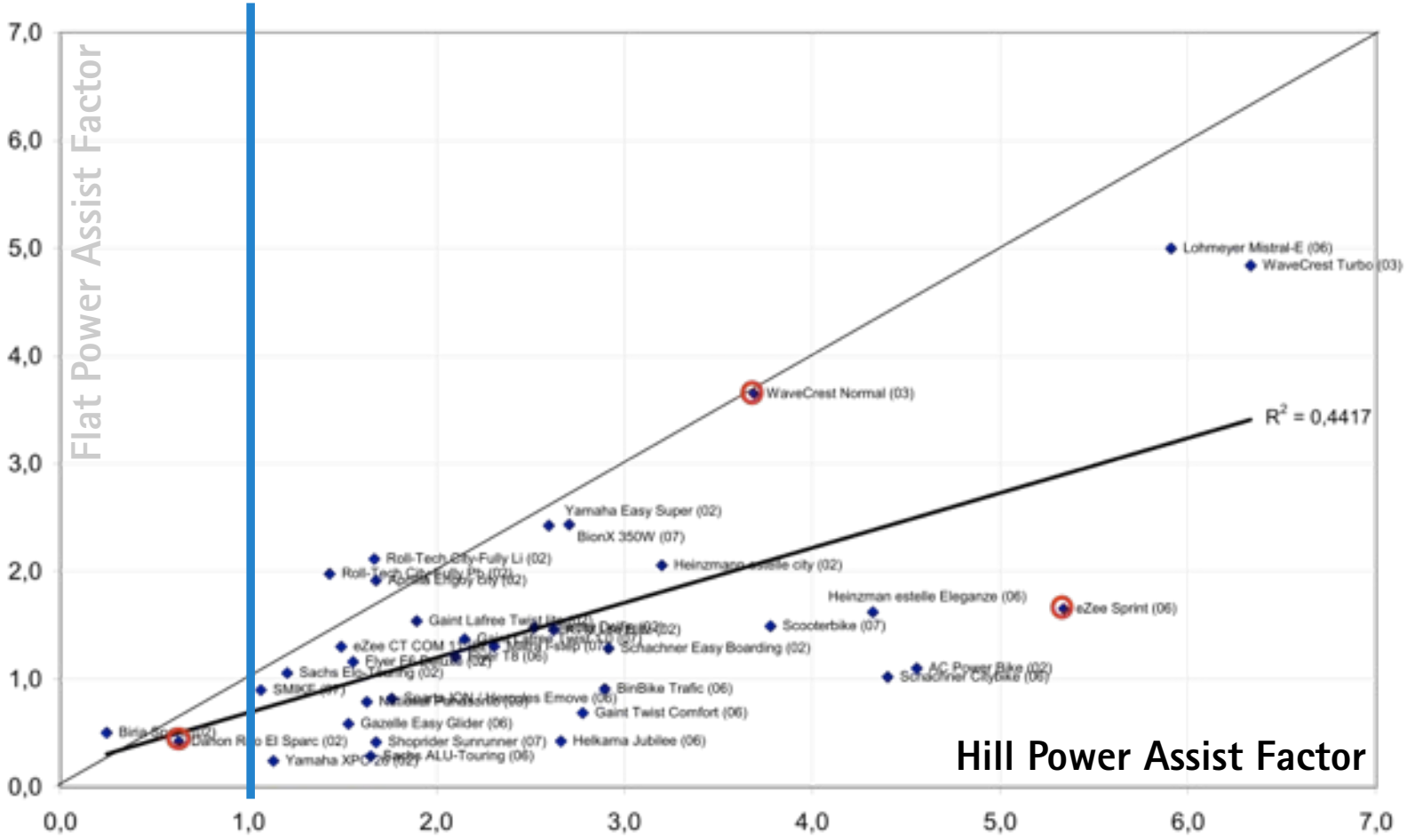
Quelle: ExtraEnergy e.V.

Assistance Faktor ... Reality



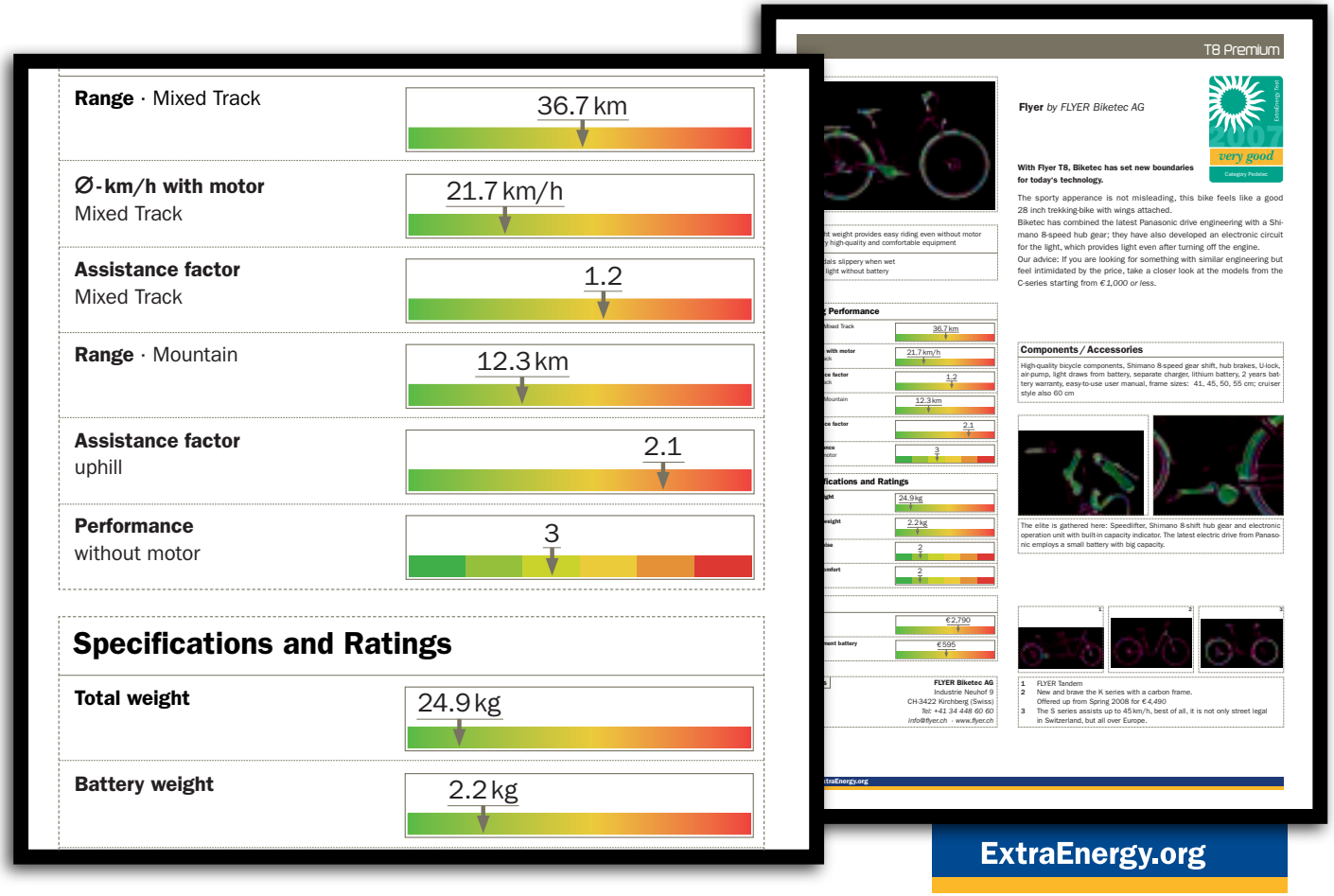
Quelle: ExtraEnergy e.V.

Assistance Faktor ... Reality



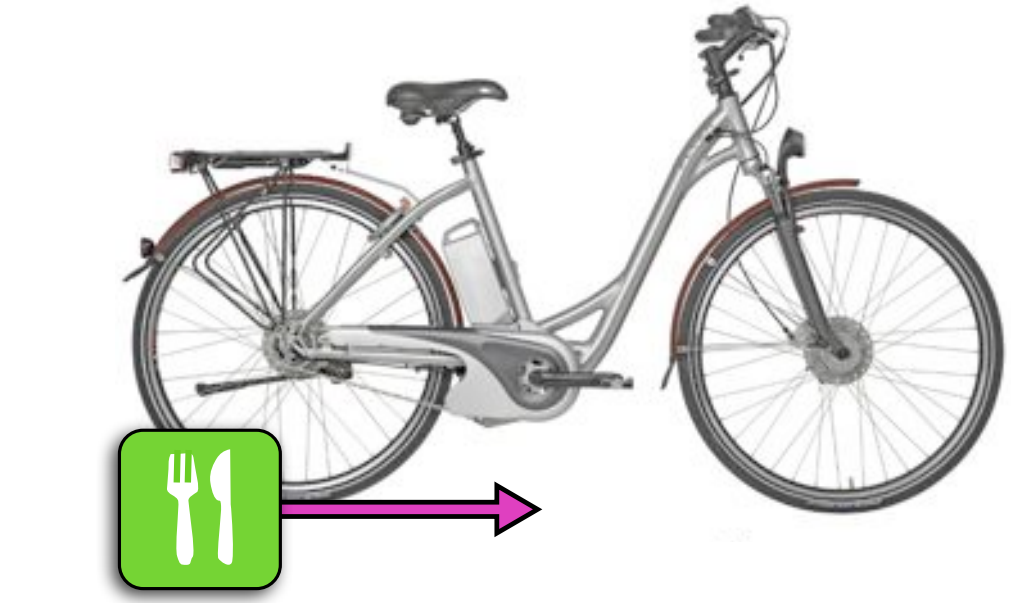
Quelle: ExtraEnergy e.V.

Assistance Factor ... A real Pedelec



Quelle: ExtraEnergy e.V.

Cycling Theory ... Assistance Factor

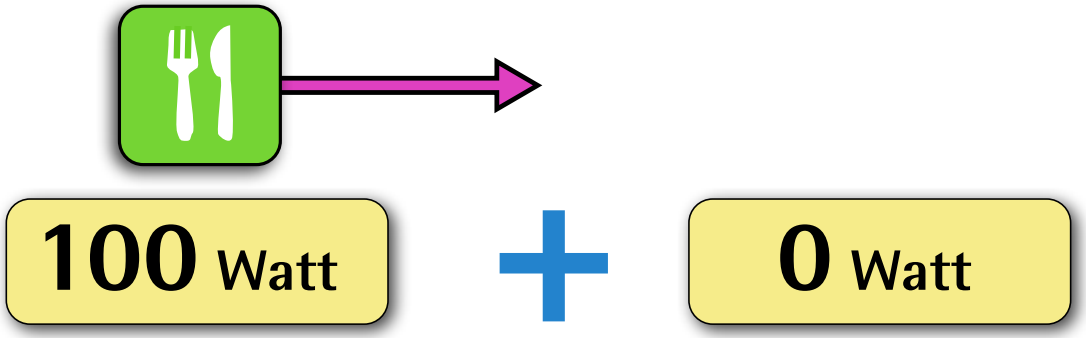


100 Watt + **0 Watt**

= **Factor 0**

Cycling Theory ... Assistance Factor

E-Motor does not help
... but still consumes energy!



= Factor 0

Cycling Theory ... Assistance Factor

But

= Factor 0

Cycling Theory ... Assistance Factor

But

Pedelecs tend to be heavier
... more power is need for the same speed!

Therefore factor calculated im comparison to regular reference bike!

ExtraEnergy.org

= Factor 0

Cycling Theory

Touring Bike

Pedelec

Cycling Theory

Touring Bike

Pedelec

Unfair ... too many advantages for the recumbent

Cycling Theory

Touring Bike

Pedelec

Cycling Theory

Rider: 175 cm, 72 kg
Bike: 18 kg
Speed: 22 km/h

Rider: 175 cm, 72 kg
Bike: 25 kg
Speed: 22 km/h
AF: 1,2

Cycling Theory

Flat

Required Power: **133 Watt**

Rider: 175 cm, 72 kg
Bike: 18 kg
Speed: 22 km/h

+ 7 kg =

Flat

+ 3 W = 136 Watt

Rider: 175 cm, 72 kg
Bike: 25 kg
Speed: 22 km/h
AF: 1,2

Cycling Theory

Hill (8 %)

Required Power: **288 Watt**

Rider: 175 cm, 72 kg
Bike: 18 kg
Speed: 12,2 km/h

+ 7 kg =

Hill (8 %)

+ 20 W = **308 Watt**

Rider: 175 cm, 72 kg
Bike: 25 kg
Speed: 12,2 km/h
AF: 2,1

Cycling "Worst Case" Theory

Pedelecs tend to be heavier
... and require up to
10% more power

288 Watt + 20 W = **308 Watt**

Cycling Theory ... CO2-Emissions

Touring Bike

133 Watt

100% E-Bike

+ 10% = **146 Watt**

At 22 km/h both require 2,7 minutes to travel 1 km

	Touring Bike	100% E-Bike
"Engine" Efficiency:	25%	70%
Required Energy per km:	24 Wh	9 Wh

Cycling Theory ... CO2-Emissions

Touring Bike		100% E-Bike
133 Watt	+ 10% =	146 Watt

At 22 km/h both require 2,7 minutes to travel 1 km

	Touring Bike	100% E-Bike
"Engine" Efficiency:	25%	70%
Required Energy per km:	24 Wh	9 Wh
GHG-Emissions per km:	36 g CO_2	10 g CO_2

1500 g CO2/kWh

1100 g CO2/kWh

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Cycling Theory ... CO2-Emissions

Touring Bike		100% E-Bike
133 Watt	+ 10% =	146 Watt

At 22 km/h both require 2,7 minutes to travel 1 km

	Touring Bike	100% E-Bike
"Engine" Efficiency:	25%	70%
Required Energy per km:	24 Wh	9 Wh
GHG-Emissions per km:	4 g CO_2	10 g CO_2

162 g CO2/kWh

Potatoes

1100 g CO2/kWh

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Cycling Theory ... CO2-Emissions

Touring Bike		100% E-Bike
133 Watt	+ 10% =	146 Watt

At 22 km/h both require 2,7 minutes to travel 1 km

	Potatoes	German-El.-Mix
"Engine" Efficiency:	25%	70%
Required Energy per km:	24 Wh	9 Wh
GHG-Emissions per km:	4 g CO_2	6 g CO_2
	162 g CO2/kWh	650 g CO2/kWh

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Cycling Theory ... CO2-Emissions

Touring Bike		100% E-Bike
133 Watt	+ 10% =	146 Watt

At 22 km/h both require 2,7 minutes to travel 1 km

	Bread	German-El.-Mix
"Engine" Efficiency:	25%	70%
Required Energy per km:	24 Wh	9 Wh
GHG-Emissions per km:	7 g CO_2	6 g CO_2
	290 g CO2/kWh	650 g CO2/kWh

Cycling Theory ... CO2-Emissions

Touring Bike		100% E-Bike
133 Watt	+ 10% =	146 Watt

At 22 km/h both require 2,7 minutes to travel 1 km

"Engine" Efficiency:	25%	70%
Required Energy per km:	24 Wh	9 Wh
GHG-Emissions per km:	7 g CO_2	0,3 g CO_2
	290 g CO2/kWh	30 g CO2/kWh
	Bread	

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Cycling Theory ... CO2-Emissions

This will be really hard

.. no butter, no jam,
no cheese, no wine ...

GHG-Emissions per km: **7 g CO_2**

290 g CO2/kWh

Bread

This is our future

0,3 g CO_2

30 g CO2/kWh

Cycling Theory ... CO2-Emissions

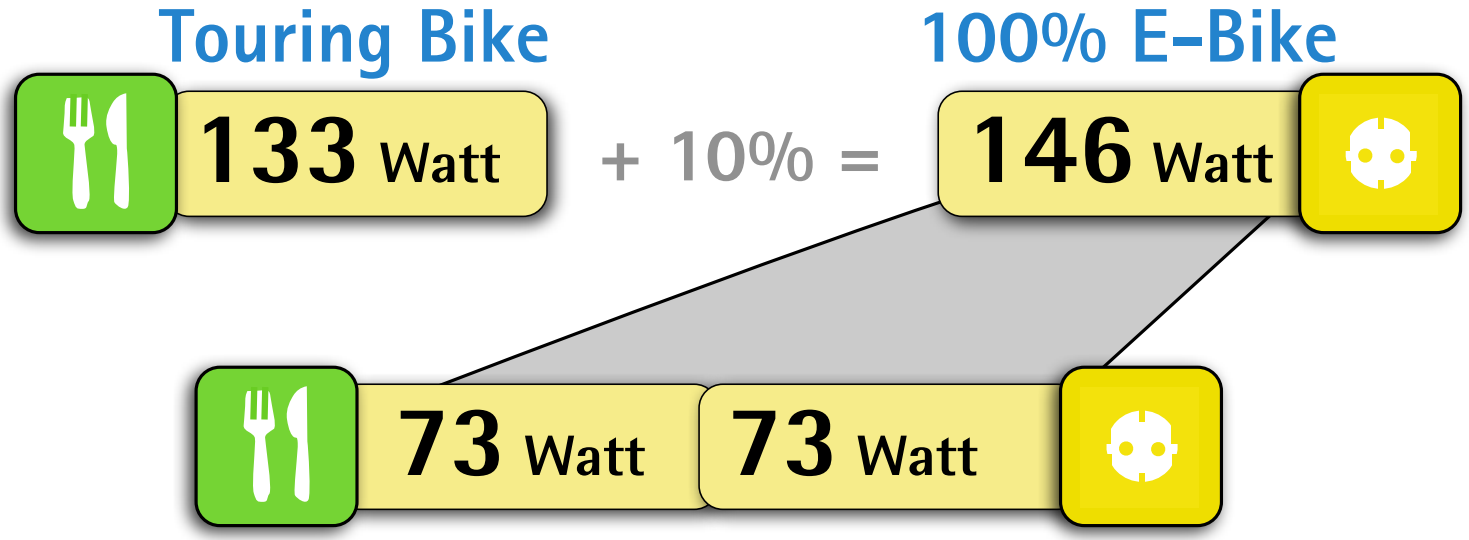
Touring Bike

+ 10% =

100% E-Bike

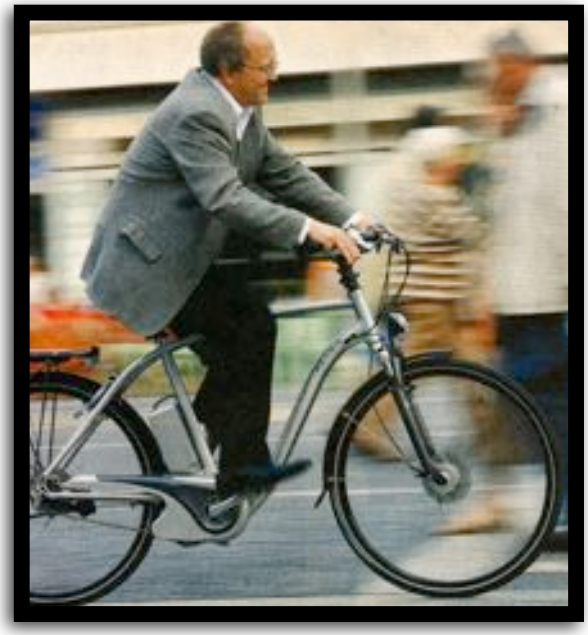
Pedelec (AF1)

Cycling Theory ... CO2-Emissions



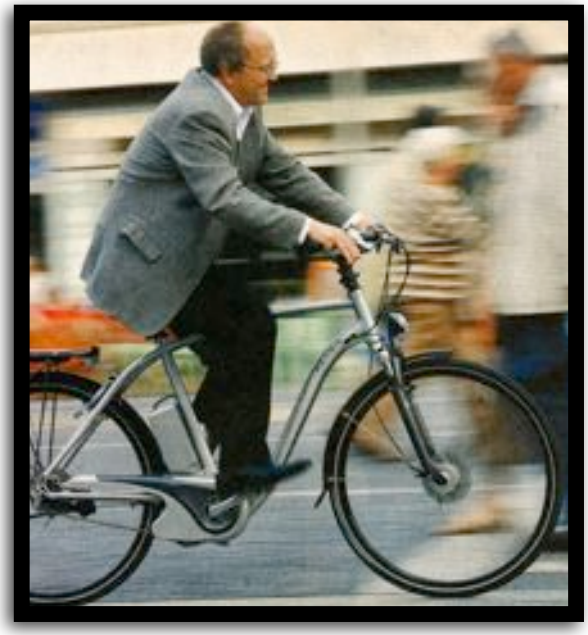
Higher emissions than E-Bike ... because it always require some “food”

This means you still can lose weight!



So ...

should we cycle less?



So ...

should we
cycle less?

We say ...

cycle more!

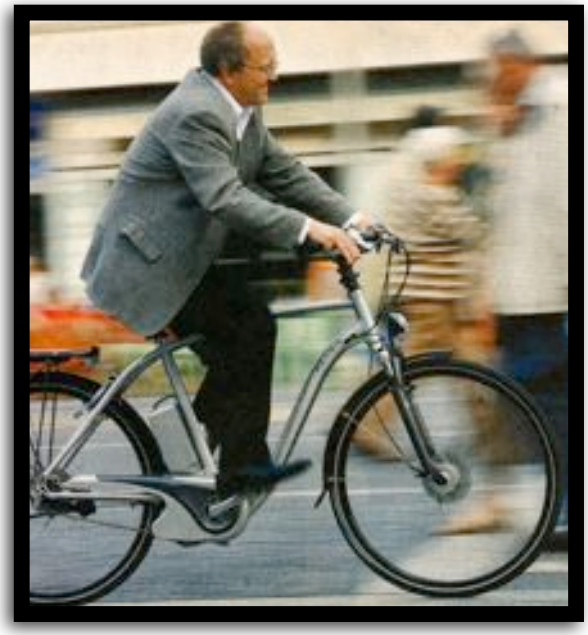
good for your health, good for your community, good for the world ... no question about that!
... but you might try to eat less meat?

Electric vehicles

Does the additional use of electricity in LEVs increase the CO_2-Emissions of our Country?

LEVs reduce CO_2-Emissions!

Pedelecs ...



250 Wh

= “real world” electricity per 33 km trip

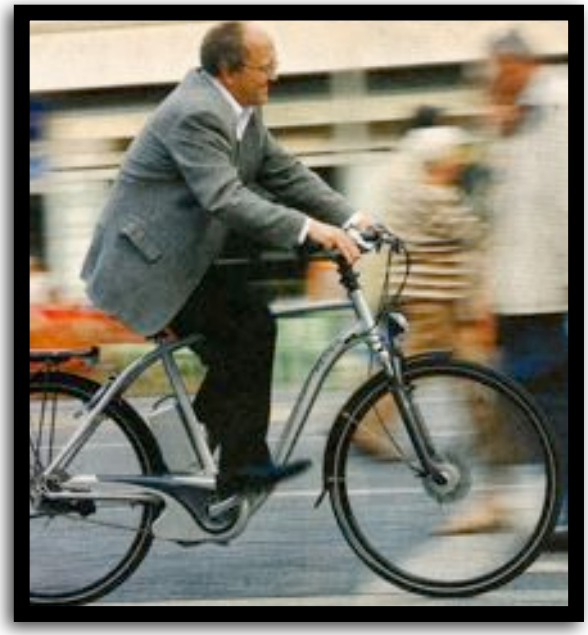
Energy ...

10 Liters * 25 Wh = 250 Wh

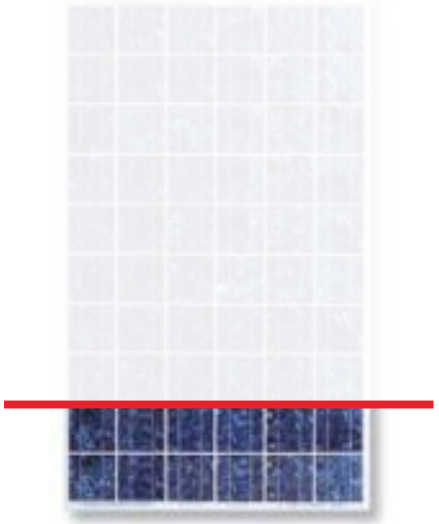
= water consumption per shower

= energy required to heat 1 liter from 15 to 40 degree Celsius

Pedelecs ...



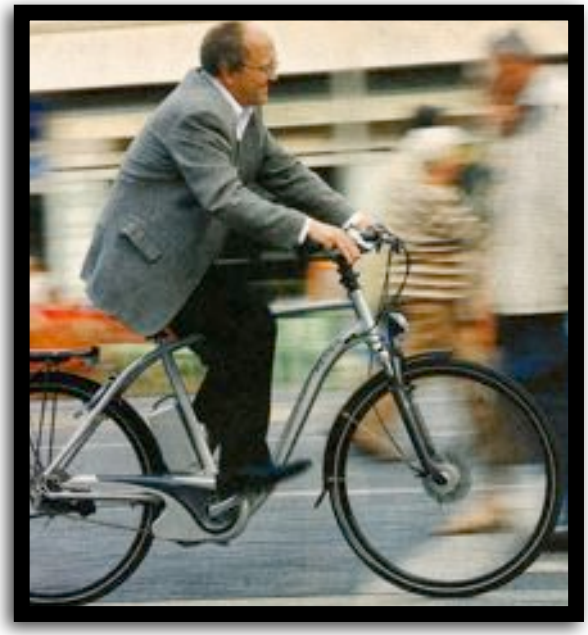
Electricity ...



250 Wh * 150 trips = 37 kWh ≡ 40 W_{peak} = 0,3 m^2

= "real world" electricity per 33 km trip	= 5.000 km per year (replacing 1/3 of all car trips)	= total consumption per year	= required power of photovoltaics panel	= required PV area

Pedelecs ...



are bringing joy
to the cyclists

Electricity ...

is not the enemy,
it is our friend

Foto: Stuttgarter Zeitung

Deutsche Gesellschaft für Sonnenenergie e.V.
International Solar Energy Society, German Section

www.dgs.de

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