How Much Energy Does it Take to Scooter 1 Kilometer?

This document seeks to form an estimate of how much energy it takes to ride a scooter 1 kilometer. This is meant to accompany a BLOSSOMS video "Quantifying the Energy in Everyday Things and Events." But the document is written to stand alone well enough for any high school student to follow.

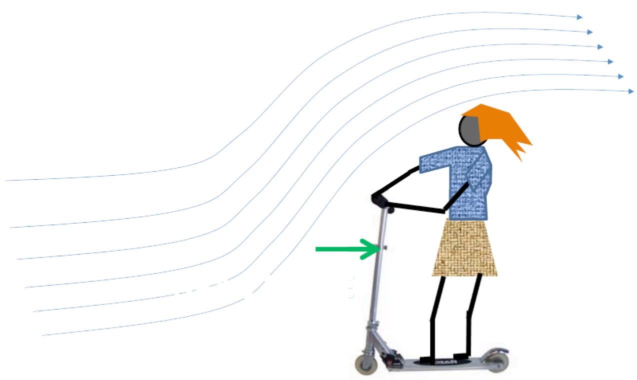
First we will need to refine the question. How much energy it takes to ride a scooter 1 km depends on many factors:

- Whether the 1 km course is flat, uphill, or downhill
- The speed of the scooter – going faster will require more energy because drag force rises with speed
- The size, and "shape" (body position) of the rider – presenting a lot of area to the flow will require more energy because drag force rises with area and is affected by shape
- The rolling resistance of the wheels which is influenced by the material properties of the wheels, and the surface and the weight of the rider
- And many other factors to a lesser degree

To help resolve such issues let's say that we want an estimate (within 20% or so) of how much energy it takes a typical eight year old girl to scooter 1 km at 5 meters per second on smooth level ground using a typical, modern kick scooter (such as a "Razor" brand scooter) with polyurethane wheels.

<u>One approach, estimating drag force:</u>

Energy required in this case could be computed by multiplying the force to maintain a constant speed of 5 meters per second times the distance (1 km). The main force arising from scootering on smooth level ground at 5m/s should be aerodynamic drag. The air passing by the girl and the bike will form streamlines to go around them and this will give rise to pressures on the surface of the girl and the scooter resulting in a net force opposite to the motion. This drag force is typically computed by engineers using a formula $D=\frac{1}{2}\rho V^2 S C_d$ where D is the force, r is the density of air, V is the velocity (speed) of the object, S is the "frontal area" of the object in the direction of the flow and C_d is the coefficient of drag.



The problem with this approach to the estimate is that you have to know a lot of facts. The density of the air at sea level is about 1 kg per cubic meter. The drag coefficient of a person standing erect is about 1.0, but along with the scooter might be a substantially higher such as 1.5. The frontal area of a typical girl is perhaps her height of maybe 1.3 m times her shoulder width of maybe 0.3 m or about 0.4 square meters. The velocity (speed) V is easy because we were given that as 5 m/s. Multiplying all that would give about 5N of drag force. Multiply by 1km to get an energy used of about 8 kJ. Because we neglected rolling resistance, the estimate must be low. Let's call 8kJ a lower bound.

<u>A very rough approach, think of an exercise machine:</u>

Some people are used to monitoring their accomplishments in fitness by looking at a calories burned meter on a treadmill or exercise bike. Let's say that scootering at a speed of 5 m/s is about as strenuous as walking at a normal pace on a treadmill. Going 1 km at 5m/s will take 200 seconds. How much energy does it take to walk for about three minutes? Well, walking at a moderate pace for an hour takes about 200 calories, so three minutes would burn 10 calories. Remember that the calories discussed in the context of eating and exercising are really kilo Calories and so there are 4kJ per dietary calorie. So, converting we get 40 kiloJoules consumed. But these figures represent what you would actually need to eat. The actual energy used is less by a large factor due to the efficiency of the body (maybe 20%?). Let's say that 40kJ is a high upper bound.

<u>An electro- mechanical engineering style approach, compare with an electric powered scooter:</u>

If you happen to have access to information about electric scooters, you might try a different approach. I saw specifications on line for a scooter. It advertised it could go at a top speed of you 23 miles per hour (that's about 10 m/s). The web page I found also says it has a 750 Watt electric motor. The power required to overcome air drag goes like the cube of the speed. So if it takes 750W to go 10 m/s, then it takes about 1/8 as much to go half as fast. In other words, it takes about 100W to go 5 m/s. To go 1km requires 200 seconds. Multiplying time and power gives energy – 200 sec times 100 W is 20 kJ.

<u>An empirical approach, find a hill and take a measurement:</u>

Another way to approach the problem is to change the scenario from what was given to one that offers some advantage is thinking about the issues or in making some simple measurements. I found it helpful to imagine a hill that would cuase a person to move along at a steady speed of 5 m/s. It was fairly straightforward to find a hill of about the right grade and measure the speed of little girls coasting down it. I found that a hill with a 5 percent grade was about what was needed to attain 5 m/s coasting. On a hill of 5 percent grade, you would go downward by 50m after going horizontally by 1km. The potential energy lost would therefore be 50m times the weight of an 8 year old girl and a scooter. I would estimate the girl and scooter weight about 400N. So the energy required by this means of estimation is 400N times 50m or 20kJ. This is my favorite estimate so far, because it was based on some measurements I made myself. I am starting to be confident in this 20 kJ estimate.