Introduction: Analysis & Modeling of Energy Systems

"The best thing to do is start simply and then build in complexity. Do the dumbest thing you can think of first."
— O'Neil and Schutt [3]

1 Analyzing energy systems

In an excellent book called *How to Solve It* [2], G. Polya presents a very general approach that can be applied to the analysis of energy systems. [My comments in brackets]

First You have to *understand* the problem. [2] [No small feat for complex energy systems!]

Second Find the connection between the data and the unknown ... You shoud obtain eventually a *plan* of the solution. [2] [If that connection isn't there, it's time to back up to your data search or collection process.]

Third *Carry out* your plan. [2] [And *evaluate* your progress as you go.]

Fourth *Examine* the solution obtained. ... Can you *check the result*? [2] [Verification/validation often require critical thinking and creativity.]

2 Working energy system problems

Many of the same techniques that are good for tackling thermal-fluid science or problems will be effective at energy systems problems.

1. Identify the system of interest.
2. Define the question you want to investigate.
3. Determine what you could measure or evaluate to address your question.
4. Determine the level of detail to start with according to the temporal and spatial dimensions of interest.
5. Decide what to measure or evaluate, starting with the simplest option(s).
6. Apply relevant methods for your model or experiment.
7. Assess what you've learned from the model or experiment.
8. Revisit the question you defined, considering whether you want to change it or investigate further.
9. Reassess the level of detail and methods, considering whether you've adequately answered the question.
10. Explain your results, documenting your methods and the analytical process itself.

The fundamental equations guiding the behavior of energy consuming or energy conversion devices often boil down to the first and second laws of thermodynamics. But the fundamental concepts of systems problems are not quite so clear–often the behavior of a number of things working together is not an obvious combination of anything.

I like the quote above ("do the dumbest thing") because they're poking a little fun at us, and engineers or scientists often seem to get ahead of ourselves. I find that often when students say, "I don't know what to do" they actually do have ideas, it's just they're not convinced they're right.

Starting with something that seems dead simple or obvious may give you a concrete starting point for your analysis or optimization, or may leave you with a new understanding that you couldn't have gained without actually trying something yourself. This holds true for building things, experimentation, analytical work and model creation as well.

3 Creating models of energy systems

In his classic modeling text *Mathematical Modelling Techniques*, Rutherford Aris defines a *mathematical model* as “any complete and consistent set of mathematical equations which is thought to correspond to some other entity.” [1] Like Aris, we will abbreviate ‘mathematical model’ to simply ‘model’ and in this course, we will often be referring to a model that is implemented computationally, where the model is some combination of code and data structures.

> The formulation of the equations of a model is usually a matter of expressing the physical laws or conservation principles in appropriate symbols. [1]

In creating (or ‘formulating’) a model, we will be concerned with the behavior over time of systems based on the equations governing energy and mass conservation and, to a lesser extent, entropy generation, as these laws describe the conversion of energy and the performance of engineered systems that convert or store energy.

4 Integrated analysis method

(i) Identify the system of interest.

(ii) Define the question you want to investigate.

(iii) Determine what you could measure or evaluate to address your question.

(iv) Determine the level of detail to start with according to the temporal and spatial dimensions of interest.

(v) Decide what to measure or evaluate, starting with the simplest option(s).

(vi) Apply relevant methods for your model or experiment.

(vii) Assess what you’ve learned from the model or experiment.

(viii) Reassess the question you defined, considering whether you want to change it or investigate further.

(ix) Reassess the level of detail and methods, considering whether you’ve adequately answered the question.

(x) Explain your results, documenting your methods and the analytic process itself.

See Figure 1, where the iterative nature of the process is illustrated graphically.

5 Important Terms

energy the currency for work, which is a force being moved through a distance, or equivalent quantity. [Units will be force × distance (also electric charge × electric potential) or power × time.]

power rate of delivering energy. [Units will be energy ÷ time.]

validation Do my results line up with observed data?

verification Did I actually do what I think I did?

References

[1] Rutherford Aris. *Mathematical Modelling Techniques*. en. Dover, 1994.

[2] G Polya. *How to Solve It: A New Aspect of Mathematical Method*. en. Princeton University Press, 2004. ISBN: 9780691119663.

[3] Rachel Schutt and Cathy O'Neil. *Doing Data Science: Straight Talk from the Frontline*. en. "O'Reilly Media, Inc.", Sept. 2013. ISBN: 9781449363901.

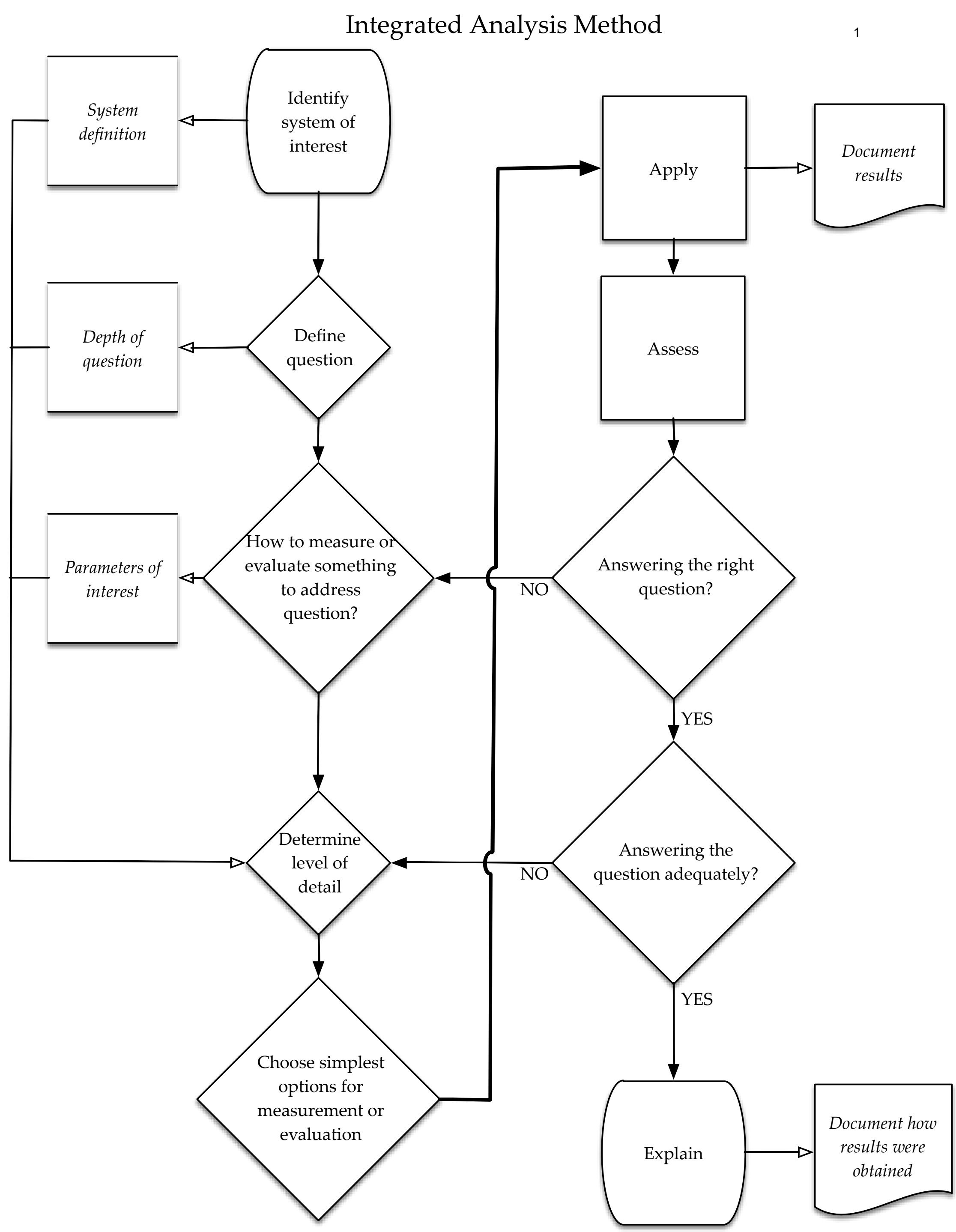

Figure 1: Integrated Analysis Method overview